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ELECTRICITY, MAGNETISM,

AND

ELECTRIC TELEGRAPHY

A PRACTICAL GUIDE AND HAND-BOOK

OF

GENERAL INFORMATION FOR ELECTRICAL STUDENTS,
OPERATORS, AND INSPECTORS.

BY

THOMAS D. LOCKWOOD.

FOURTH EDITION

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INTRODUCTION.

ELECTRICITY is pre-eminently a science of the nineteenth century.

We cannot even at this late day say that we know what electricity is; and within a comparatively recent period even its manifestations and phenomena were familiar to a relatively small class, composed chiefly of college professors and scientific lecturers.

Few of the class which was entrusted with the management of its practical applications—viz., telegraphers and electro metallurgists—had any scientific knowledge of its laws, or, in fact, anything but a mechanical and empirical knowledge of the manipulation of the telegraph instrument and the electrolyzing battery.

This state of things has, however, passed away, and electricity has become the favorite, most promising, and most important scientific study of that section of the human race which, under the title of inventor, aspires to achieve fame or fortune, or both, by the work of its own brains.

During the last decade we have seen such wonderful developments in electricity and electro-magnetism that while on the one hand we can scarcely conceive of anything which cannot be done by these agencies, on the other hand we are almost compelled to believe that there is little more left for electricity to achieve.

It is true that for many of the greatest discoveries

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and inventions which have been made we are indebted to persons who have not been practical electricians, but it is also true that it is to the practical electrician we turn when these discoveries are to be utilized; and it is to be regretted that among the thousands of our telegraphers and telephonists so few are to be found capable of assuming an important trust, and of practically and ably filling important positions in the many applications of electricity.

A general knowledge of the theory and practice of electricity and magnetism is, then, a most desirable and valuable acquirement for all who are in any way, or who intend to be, connected with the practical application of either science.

And this desirability, and the knowledge that but few of the many books written upon the subject are fitted for the self-helper, who has to struggle against many difficulties, notably that of neglected early education, forms the excuse of the author for inflicting another book upon the electrical public.

Imperfect as this volume is in many ways, such a one would have been a great help to the author had he in his earlier years had the fortune to stumble across it, and it is his earnest hope that its contents will in some measure aid those for whom it is written—those who desire to obtain a knowledge of electricity and magnetism and their possibilities, but who are unable to obtain the advantages of a college or institution course—and enable them to answer for themselves the innumerable questions which constantly force themselves upon the thinking mind when daily occupied in the utilization of these mysterious agencies. If the readers of this work learn but one tithe as much of the various subjects treated of as the author has while working upon it, they will be benefited, and will perhaps be more ready to digest the more solid contents of such standard books as Culley's "Hand-book of Practical Telegraphy" and Fleeming Jenkin's "Electricity and Magnetism."

The author has endeavored to put the information in as lucid and concise form as is consistent with accuracy, and to combine brevity with completeness. How he has succeeded is for others to judge. A liberal use has been made of the electrical text-books, and of the literature relating to kindred subjects, also of the current electrical journals of the day; and valuable information has especially been obtained from the well-known "Modern Practice of the Electric Telegraph" by Mr. Pope; Culley's "Hand-book of the Electric Telegraph"; Prescott's "Electricity and the Electric Telegraph"; Preece and Sivewright's "Telegraphy"; and "Elementary Lessons in Electricity and Magnetism," by Silvanus P. Thompson.

The acknowledgments of the author are also due to his friend Frank L. Pope for his constant advice and encouragement during the preparation of the work.

CONTENTS.

PAGE

CHAPTER I.

Electricity generated by Friction, ... 9

CHAPTER II.

Voltaic Electricity, ... 22

CHAPTER III.

Thermo-Electricity, ... 36

CHAPTER IV.

Earth-Currents and Earth-Batteries, ... 41

CHAPTER V.

Magnetism—Electro-Magnetism and Electro-Magnets, . . 43

CHAPTER VI.

Magneto-Electricity, and Magneto and Dynamo-Electric Machines, ... 59

CHAPTER VII.

Induction-Coils and Condensers, ... 80

CHAPTER VIII.

Definitions of Electrical Properties, Terms, and Units, . . 89

CHAPTER IX.

Electrical Measurements, ... 98

CHAPTER X.

Principles of Telegraphy exemplified in Different Systems, . 130

CHAPTER XI.

Voltaic Circuits, ... 142

CHAPTER XII.

PAGE
Line Construction, ... 153

CHAPTER XIII.

Subterranean and Submarine Conductors, ... 184

CHAPTER XIV.

Office-Wires, and Fittings and Instruments, ... 192

CHAPTER XV.

Adjustment and Care of Telegraph Instruments, . . . 222

CHAPTER XVI.

Circuit Faults and their Localization, ... 231

CHAPTER XVII.

Multiple Telegraphs, ... 242

CHAPTER XVIII.

Miscellaneous Applications of Electricity—Electric Lighting, . 266

CHAPTER XIX.

Electro-Metallurgy, ... 281

CHAPTER XX.

Electric Bells, ... 286

CHAPTER XXI.

The Telephone, ... 299

CHAPTER XXII.

Electro-Therapeutics, ... 318

CHAPTER XXIII.

Other Applications of Electricity:—Electric Clocks—Time-Balls —Alarms—Blasting—Transmission of Power—Electrical Storage, ... 323

CHAPTER XXIV.

and Ends, ... 351

ELECTRICITY, MAGNETISM, AND TELEGRAPHY.

CHAPTER I.

ELECTRICITY GENERATED BY FRICTION.

1. *What is electricity?*

Electricity is one of the peculiar forces of nature; it is as universal in its effects as its kindred forces, light and heat, and is in many respects analogous to them. It has been common to speak and write of electricity as if it were a fluid, capable of flowing as a current. It is, however, now usually considered by scientists to be simply a particular form of energy,* which causes the infinitesimal particles of matter to alter their positions in regard to one another.

2. *From whence does electricity derive its name?*

It was observed in ancient times that when amber† was rubbed it acquired a power of attracting and repelling light bodies, such as hair and feathers. This power afterwards came to be called electricity, from "electron," the Greek word for amber.

3. *Why has it become customary to speak of electricity as if it were a fluid, and consequently subject to the laws of fluids?*

Because for many years it was in fact thought to be a fluid. The fluid theory was first propounded by

---

*Energy in a mechanical sense may be defined as capacity for performing work or for moving against resistance.

†Amber is a resin of yellowish color resembling copal, found as a fossil. It takes a fine polish and is used for ornaments and also as a basis for a superior quality of varnish.

Du Fay, of France, who supposed that there were two electric fluids, naturally commingled and neutralized, which universally pervaded all matter. Dr. Benjamin Franklin proposed a second hypothesis, ascribing all observed electrical effects to one fluid, which, as in the former case, was supposed to pervade all bodies. According to Franklin's theory, it was supposed that the electrical equilibrium or balance constituting the natural state of matter was disturbed by friction, and that one of the two bodies brought near to each other, was, so to speak, over-saturated with electricity, while the other was left under-saturated. This also explains the origin of the terms plus and minus as applied to opposite electrical states or conditions. As the terms which have come to be adopted in speaking of electricity and its properties are nearly all based on the foregoing theories, and have in this manner become familiar to men of science everywhere, it has by common consent been considered unwise as well as unnecessary to change them.

4. *What is the simplest method of producing electricity?*

By rubbing together two suitable substances, such, for example, as a tube or rod of glass and a woollen cloth. Electricity so produced is called *frictional electricity.*

5. *Is not electricity produced in different states or conditions?*

Yes. Certain substances, such as sealing-wax and resin, when rubbed by a woollen cloth, exhibit what Dufay called resinous electricity; while glass or other vitreous bodies, when rubbed with the same cloth, exhibit a kind which he called vitreous electricity. These names are, however, quite unsuitable, as they imply that the same substances always produce the same kind of electricity, irrespective of conditions; whereas a tube of glass, when rubbed by the fur of a cat, produces the same kind of electricity as sealing-wax. The terms positive nd negative are less objectionable, and are still very rally employed.

We may, therefore, call the electricity produced by rubbing glass with a woollen cloth positive, and denote it, for the sake of brevity, by the sign plus, or + ; and that produced on a stick of sealing-wax, when rubbed, negative, and denote it by the sign minus, or —. These terms, however, must not be understood to indicate that one electricity is more powerful or potent than the other; they are purely arbitrary, and merely used for the sake of distinction, to denote that the two electrical states are opposite in character. Both kinds of electricity are always produced at the same time and in equal quantities, one of the bodies rubbed exhibiting plus and the other minus electricity.

6. *What is an electrical conductor?*

Conductors are those bodies and substances which permit electricity to freely diffuse itself through them. All the known metals are good conductors. Many non-metallic substances are also conductors. The inherent conducting power of bodies depends largely upon conditions; for instance, ordinary water when in liquid form is a conductor, but when frozen becomes a non-conductor. Iron, when cold, is a good conductor; when hot, a very poor one.

7. *What is an insulator, or non-conductor?*

Bodies which offer very great resistance to the passage of electricity, such as dry air, paraffine, gutta-percha, india-rubber, and glass, are called non-conductors, or insulators, from *insula*, an island. There is no absolute distinction between insulators and conductors. The difference is in degree only, all bodies being, strictly speaking, conductors in a greater or less degree, the worst conductors being the best insulators. Hence a list of conductors, arranged in the order of their conducting power, becomes, if read backward, a list of insulators, and in the middle of the list the conductors and insulators merge insensibly into each other.

8. *Define the terms "electric" and "non-electric," which are sometimes applied to substances.*

It was formerly considered that insulators were the only bodies upon which electricity could be excited, hence they were also denominated electrics; while the conductors, such as the metals, were called non-electrics. This supposition was, however, an erroneous one, as, when properly insulated, the most perfect conductors can be electrified. The distinction between electrics and non-electrics is, therefore, no longer admissible, although the terms are still frequently used in works on electricity.

9. *What is an electroscope?*

An instrument for indicating the presence and character of electricity. A gold-leaf electroscope consists of a glass vessel, B, into which is inserted a metallic rod terminating in two gold leaves, *n*, and surmounted by a metallic plate or ball, C. If the plate is touched by an electrified body, A, the excitement passes down to the leaves and causes them to repel each other, or to diverge. An instrument provided with means of measuring the amount of divergence, and thereby measuring the amount of electricity present, is called an *electrometer*.

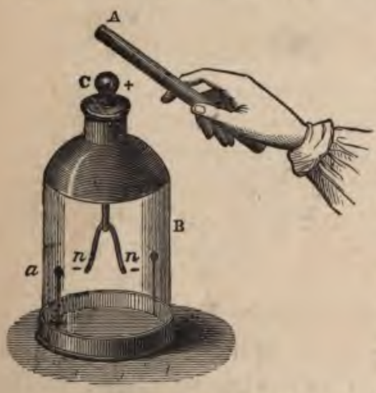


Fig. 1.—The Electroscope.

10. *What is an electrical machine?*

It is an apparatus for obtaining large quantities of electricity, usually by the friction of an extended surface of some suitable non-conductor, such as glass or hard rubber.

In order that glass may be conveniently subjected to ion for the development of electricity, it is formed into a circular plate, P, mounted on an axis supported on a wooden frame, O, and revolved by a crank, M, while cushions or rubbers, F, press against its surface. To equalize the pressure of the rubbers they are placed at the top and bottom, and on both sides, of the glass. In front of the plate are two rods of metal, C, supported by glass legs. These are called the prime conductors, and are provided with branches, which are studded with sharp points and bent round the glass plate.

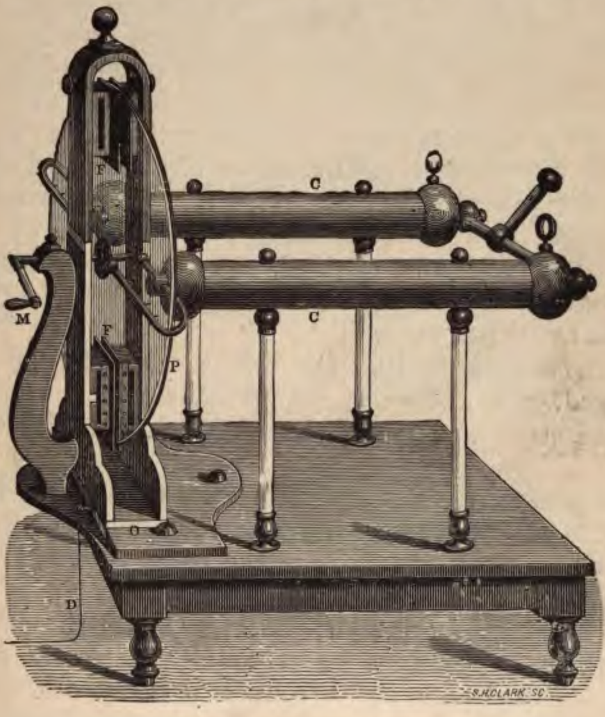


Fig 2.—The Electrical Machine.

When the plate is revolved by means of the crank, by reason of the friction against the cushions it becomes positively electrified; negative or minus electricity being at the same time produced in the rubber. When the plus electricity, carried round by the rotation of the plate, arrives opposite the points of the prime conductor, it acts inductively thereon, repelling its plus electricity to the distant end and attracting minus electricity to the end nearest the machine. The points then discharge the minus electricity so accumulated towards the plus charge on the revolving plate, which is thus neutralized, and the neutralized portion of the plate arrives at the rubber in a neutral state and ready once more to be excited. If now any electrically neutral substance be brought near to the distant end of the prime conductor, minus electricity will be abstracted from it and will pass along the conductor to keep up the supply necessary for a continuous neutralization of the excited plate; hence the prime conductor, and any conductor attached or brought near thereto, will acquire a surplus of plus electricity, or become charged, and this charge may be conducted away or collected in Leyden jars at will for experimental purposes.

If it is desirable that the minus electricity be also collected, the rubber is supported upon a non-conducting stand and provided at the back with a metallic knob.

But generally, the negative or minus electricity is allowed to pass to earth or to the surrounding conductors, such as the walls and floor of the room, by means of a chain or wire, D.

In charging a Leyden jar, the rubbers and the outside coating of the jar must be united either directly, or by being both united to the surrounding conductors.

Another common form of the electrical machine is the *cylinder*. The chief distinction between this and the plate machine lies in the use of a cylinder of glass instead of a plate.

11. *What is an electrophorus?*

It is an instrument, invented by Volta, which is an exceedingly convenient source of electricity when required in comparatively small quantities. It consists of three essential elements: 1st. A cake, B, of some resinous material easily excited by friction. 2d. A conducting plate, which is a metallic dish into which the resinous composition is poured, and which is connected to earth. 3d. A disc of metal, or of wood covered with tin-foil, A, and provided with an insulating handle.

It is very convenient to so arrange the electrophorus that the cover, when placed on the resinous plate, comes into metallic connection with the metal dish below, and thereby, of course, with the earth. The resinous cake is excited negatively by rubbing, and the metal plate laid upon it; on lifting it away it is found to be positively electrified and will give a spark. It may then be replaced on the lower plate and the process indefinitely repeated.

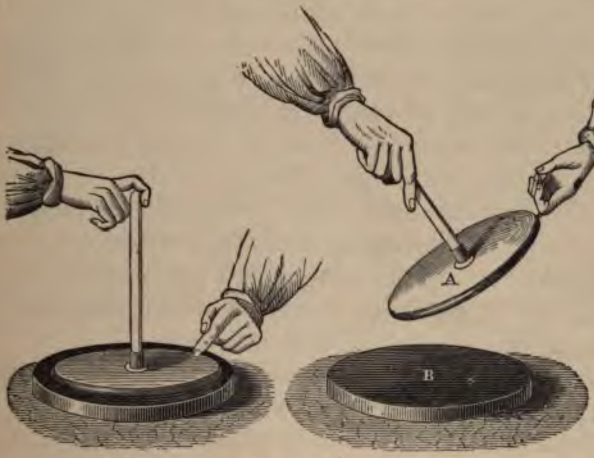


Fig. 3.—The Electrophorus.

The upper plate does not receive its charge direct from the excited resin, but by induction, the negative charge on the resin attracting the positive and repelling the negative electricity of the upper plate which, by means of the metal connection with the lower plate or by the touch of the finger as in the figure, escapes to earth. Instead of pouring a resinous composition into the dish, a flat piece of vulcanite may be fixed therein to subserve the same purpose.

12. *Have machines for furnishing large quantities of electricity been constructed on the principle of the electrophorus?*

Yes, such machines have been constructed by several physicists; and one—that of Holtz—has come into very general use. In it, as in other machines of this class, a small initial charge is given to a piece of varnished paper fixed on a stationary portion of the machine.

This initial charge acts inductively and develops other charges, which are conveyed by a rotating glass disc to some other part of the machine, where they may either increase by accumulative action the initial charge or furnish the supply of electricity to a suitable collector; or the machine may be caused to perform both functions, much upon the same principle as that of the dynamo-electric machine. (See chapter vi.)

Like the Gramme and other continuous-current machines, it, too, is reversible; and if a continuous supply of both plus and minus electricities be supplied simultaneously to the opposite extremes of the machine, the movable parts of the machine will rotate.

A Holtz machine may be made to furnish a continuous current, the strength of which is dependent upon the rate at which the movable part is rotated, becoming greater when the rotation increases in speed.

13. *What is the meaning of the words "static" and "dynamic" when applied to electricity?*

They are derived from the Greek. The word "static" conveys the idea of force at rest, and "dynamic" the idea of action or of force due to motion. Electricity developed by friction is often called "statical," because it tends to remain quiescent on the bodies whereon it is excited, or in fact wherever it is placed.

The word *static*, or *statical*, refers to the electrical ndition of bodies whereon electricity remains station- For instance, a Leyden jar may be charged, and harged without requiring a continual supply to be poured in; hence the electricity it is charged with is called statical, or reposing, electricity. On the other hand, voltaic electricity is frequently styled *dynamical*, because the excitement arises in a constant stream, and can hardly be said to exist if it is not continually evolved, and in that condition it exercises or performs work; and statical electricity becomes transformed to dynamical when in the act of discharge, or when passing from one body to another.

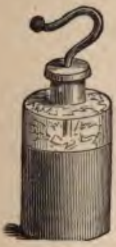


Fig. 4. Leyden Jar.

14. *What is a Leyden jar, and whence does it derive its name?*

It is a device for the accumulation of electricity, and, described as simply as possible, consists of a glass jar coated both inside and out with tin-foil, except a few inches at the top. Through the cork or insulating cover is passed a brass rod with a knob on the end, which is in electrical communication with the inner coatings.

It was discovered in November, 1745, by Kleist, a German ecclesiastic. The Leyden philosophers were the first to state the conditions necessary for its success, and hence it received the name Leyden jar. The jar is charged by bringing the knob near to the prime conductor of the electrical machine, while the outer coating is usually in electrical communication with the earth. When the knob is brought into connection with the outside coating of the jar a flash of intense brightness, accompanied by a loud report, immediately ensues, and the jar is said to be discharged.

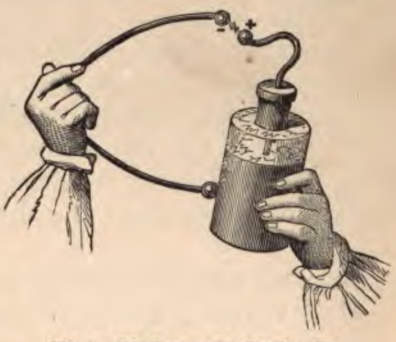


Fig. 5.—Discharge of a Leyden Jar.

15. *What does the term "dielectric" imply?*

The insulating substance which separates two conducting surfaces, and thereby enables them to sustain opposite electrical states, was by Faraday called a dielectric.

The sheets of paraffined paper between the tin-foil sheets of a condenser, constitute a familiar example of a dielectric. All insulators are dielectrics, but the best insulators are not always the best dielectrics.

The glass jar between the inside and outside coatings of tin-foil is, in a Leyden jar, the dielectric.

16. *What is an electric battery?*

When a great amount of surface is needed to store a considerable quantity of electricity, a number of jars are set in a box lined with tin foil so as to connect all the outer coatings together. Their inner coatings are also connected by conductors joining all the knobs to one central knob. This constitutes an *electric battery.* It is charged and discharged like a single jar, and its effect is much the same as would follow from one large jar whose extent of coating was equal to the sum of those which constitute the battery.

17. *Does static electricity reside at the surface, or throughout the substance of bodies?*

Electricity at rest, resides on the surface only of conductors. This may be proved by enclosing an electrified metallic sphere in two tight-fitting, non-electrified hemispheres. If the hemispheres are quickly removed and presented to an electroscope they will be found to be electrified, while the sphere itself has lost its electricity.

18. *What may we understand by the word "induction"?*

It is the name given to electrical or magnetic effects produced in bodies to which the exciting force is not directly applied, and may for general purposes be divided into the following heads: 1st. *Electro-static* or *static induction* is the influence which an electrified body has on all conducting bodies in its immediate vicinity, even though it has not touched them, causing them to exhibit signs of electrification. It is similar to the power exerted by a magnet on pieces of iron which may be near it. 2d. *Dynamic* or *voltaic induction* is the power which a galvanic current has, when flowing in a conductor, of inducing currents in neighboring conductors.

For example, should two wires be placed near each other, parallel but not touching, one connected with a battery by means of a circuit-closing key, the other to a sensitive galvanometer, it would be seen that whenever the circuit was closed by the key on the first wire, and a current thereby caused to pass through it, the galvanometer attached to the second wire is deflected by a current flowing in the opposite direction to the battery current.

The battery current is called the inducing or primary current; the current that deflects the galvanometer the induced or secondary current. The induced current lasts but for an instant. When, however, contact is once more broken the needle is again deflected, but this time the induced current flows in the same direction as the primary current, and is, like the former current, instantaneous.

3d. *Electro-magnetic induction* is the power which an electric current, traversing a conductor, has upon non-magnetized iron, which, under certain conditions, may by its influence become converted into a magnet.

This power is the basis of one of the most universally useful applications of electricity—namely, the *electro-magnet*.

4th. *Magneto-electric induction* is the converse of electro-magnetic induction—the one is the induction of magnetism by an electric current, the other the induction of an electric current by a magnet.

The name is popularly applied to the production of electric currents through the movement of a conductor through a magnetic field, or the movement of a permanent magnet in the immediate proximity of a conductor.

5th. *Magnetic induction* is that power by which pieces of iron, or other substances capable of acquiring magnetism, become temporary magnets when placed near a magnet, even when they do not touch it.

19. *Has frictional electricity been put to any practical application?*

Yes; but not to any such extent as voltaic electricity. It has been somewhat extensively used in chemistry, and has been applied with considerable success for igniting gas-jets and fuses for blasting.

20. *Is friction the only method of producing electricity?*

No; there are many other methods of evolving it, but chemical action is by far the most important source of electricity, and is the only one that has had a universal practical application in telegraphy. More recently, however, *magneto-electricity* has attracted much attention, and has been considerably applied to telegraphy, electro-metallurgy, and to the production of the electric light.

The production of electricity by heat constitutes a separate branch of the subject—namely, *thermo-electricity*, which will be hereafter considered.

21. *What is the most familiar natural form of electricity?*

Atmospheric electricity, in the form of the thunder-cloud with its resultant phenomena of thunder and lightning. The resemblance between lightning and the electric spark was noticed at an early date. Dr. Wall pointed this out in 1708, and it has also been noted by other philosophers; but to Benjamin Franklin is due the credit of proving their identity by actual experiment, in drawing lightning from a cloud by the instrumentality of a kite, and by performing electrical experiments with it.

22. *Had this discovery any useful result?*

Yes, it has resulted in the general application of the *lightning-rod* as a method of defending buildings from the effects of atmospheric electricity. The lightning-rod is constructed on the principle that electricity uniformly chooses the best conductor within its reach, and consists of a rod of iron or copper, from half an inch to an inch in diameter, extending a considerable distance above the highest point of the building, and continued down the wall to terminate in the ground.

23. *What is the most common defect in the construction of lightning-rods?*

They are frequently set up with a very imperfect connection with the ground, hence the lightning, finding a better conducting medium through some portion of the building, takes that path, often with most destructive results. The rod ought always to terminate in a considerable depth of moist earth, and for this reason none should engage in the business of constructing and erecting lightning-rods unless they are well acquainted with the principles of electricity.

CHAPTER II.

VOLTAIC ELECTRICITY.

24. *What is voltaic or galvanic electricity?*

These names are given to electricity evolved by *chemical action.* They are so called in honor of Galvani and Volta, two Italian philosophers who made the earliest discoveries in this branch of the subject. As previously stated, this is sometimes called dynamical or current electricity, because it is electricity in motion.

25. *What are the chief points of difference between voltaic and frictional electricity?*

While voltaic electricity resembles the electricity generated by the frictional machine in a sufficient degree to establish its identity therewith, its characteristics, nevertheless, differ materially. Electricity evolved by a battery is of low potential or tension, and is, therefore, comparatively easily insulated. It flows in a steady and continuous current, and is produced in great quantities. On the other hand, in the frictional form, electricity is extremely energetic, being able to transfer itself violently (and with the evolution of light and heat) through and over insulating substances. It is, therefore, said to be of high potential.

Voltaic electricity is capable of producing the most extensive magnetic and chemical effects, and is consequently by far the most important form and the most valuable agent in the arts and sciences. To sum up: frictional electricity has high potential, but is produced in small quantity, while current electricity has an ex-
emely low potential and is produced in large quan-
es. This may be illustrated in the following manner:
l-hot iron rod has intensely high temperature, yet

it does not contain nearly so much actual heat as the water of a single hot bath. The electricity of friction may be compared, therefore, to the heat of a red-hot iron rod; that of chemical action to that of a large volume of warm water.

26. *What is a voltaic or galvanic cell?*

An organization whereby chemical energy is transformed into electricity. Its simplest form consists of two dissimilar metallic plates, immersed in some liquid capable of acting chemically upon one more than upon the other. The surface less acted upon is called the *negative* plate, and that more acted upon the *positive* plate. Zinc is almost always used as the positive plate, and the difference of potential, and consequently the electro motive force, is the greatest when there is no chemical action on the negative plate. The positive electricity is assumed to set out from the zinc, pass through the liquid to the negative plate, and thence by a connecting wire back again to the zinc. Such a cell is called a simple battery, and has one great disadvantage—namely, that when its circuit is closed, by connecting its poles by a wire, its action rapidly diminishes; it becomes *polarized.* Many cells have been devised, chiefly with a view of diminishing or suppressing this fault of polarization, and thereby increasing the constancy of batteries.

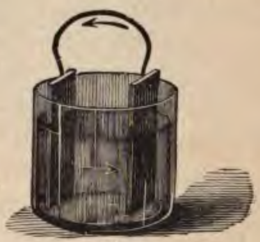


Fig. 6.

27. *What is meant by the term "polarization" when applied to voltaic cells?*

We know that water is a chemical compound of two gases, oxygen and hydrogen. When the circuit of a simple zinc and copper battery is closed, chemical action commences and the water is decomposed, the oxygen attacking the zinc and eating it away, while the hydrogen deposits itself on and covers the surface of the copper plate, and, in fact, assumes nearly the same relation to the zinc as if it were a zinc itself, the result being much the same as if two zinc plates were opposed to each other. A new electro-motive force is developed in opposition to the original electro-motive force of the battery; the working is impeded and the strength of current diminished. To this deleterious action is given the name of *polarization.*

The injurious effects of polarization are increased by the power which hydrogen in this form has of reducing metals from their solutions ; for as soon as the sulphate-of-zinc solution formed by the action of the acidulated water on the zinc plate has diffused itself through the liquid so as to reach the copper, it is decomposed by the before-mentioned hydrogen, and metallic zinc is deposited on the copper plate. This also tends to transform the battery into one wherein both plates are zinc.

To render a battery constant (which means to furnish a steady and equal current during the time for which it works) polarization must be prevented. This object is attained in different ways ; in the Daniell battery, for example, by surrounding the negative plate with a strong solution of a salt of its own metal. This expedient keeps the free hydrogen actively employed in reducing copper from the sulphate-of-copper solution and depositing it on the copper plate, and consequently restrains it from assuming a gaseous form and coating the copper plate ; and, further, as the metal reduced is the same as the plate itself, the battery gains instead of loses, because the surface of the plate, by the metal added, is kept new and bright.

28. *What is a voltaic battery?*

When a series of voltaic cells are connected together as shown in Figure 7 the combination is called a *voltaic battery*, just as a combination of Leyden jars is designated an electrical battery. The several elements of a battery may be connected together in several different ways, and this is regulated by the character of the work which the battery is required to do.

A voltaic battery, to approach perfection, should be simple in construction, easily prepared and maintained, have a sufficiently high electro-motive force, be fairly constant, tolerably free from local action, economical in first cost, and consist of materials which are easily procured.

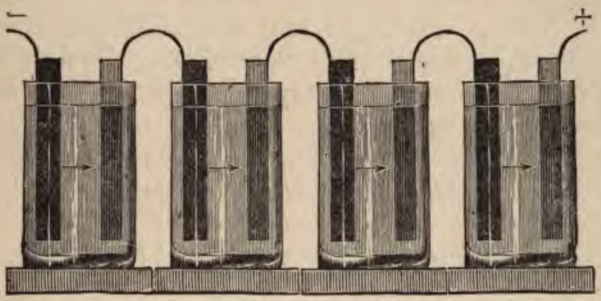


Fig. 7.

29. *What is meant by the term "local action"?*

It is a name given to chemical action which takes place in the battery, whether there is or is not any external metallic connection between the plates, or, in other words, whether the circuit is closed or open. It goes on at the surface of the zinc, and consumes that metal without aiding in the production of the working current. It is supposed to arise from the presence of impurities in the zinc, on account of which one portion of the metal is in electrical opposition to the other, thus producing local currents, causing evolution of hydrogen at some points and consumption of the zinc at others. This evil is remedied to a great extent by *amalgamating* the zinc plate. The surface of the metal is thereby reduced to the same condition at all points, and differences of hardness, softness, and crystalline structure are eliminated. The amalgamation of battery zincs is effected by simply rubbing them with mercury, after they have been thoroughly cleansed by immersion in dilute sulphuric or muriatic acid.

30. *Why is a voltaic battery sometimes called a "pile"?*

Because the first arrangement constructed by Volta for evolving current electricity consisted of a great number of round pieces of zinc, copper, and moist cloth, piled alternately one upon another, as in Figure 8. It was literally a pile of discs, and the name, from early associations, is still used (chiefly, however, by French electricians), though it has now entirely lost its special significance.

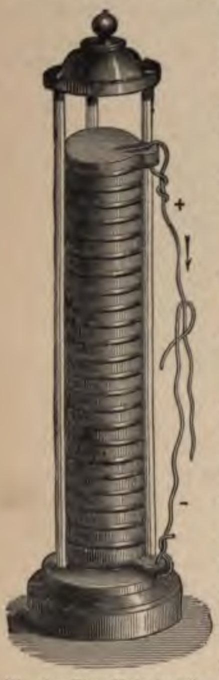


Fig. 8.—The Voltaic Pile.

31. *Under what general heads may nearly all voltaic batteries be classified?*

Single-fluid batteries, of which that of Smee may be taken as a type.

Two-fluid batteries, which may properly be subdivided into three classes. Of the first class the well-known Daniell is the representative. The second subdivision comprises the numerous forms of gravity battery, from the Callaud to the Watson. In the Watson battery an inverted leaden funnel is used as the negative plate, and also as a repository for the copper sulphate. The third subdivision includes the strong-acid batteries, such as Grove's and Bunsen's.

The third great class is that wherein depolarizing mixtures are used. These preparations are made from different oxides and chlorides. The Leclanché battery is the best-known and most notable example.

32. *What batteries are now in most general use?*

In America the principal forms used are: the gravity, chiefly Callaud's form (although every other type finds its advocates); the Grove, the Daniell, the chromic-acid, the Leclanché, and the Smee.

In England the Daniell and Leclanché are used for telegraphs, and the Grove and Bunsen for other practical purposes.

In France the Leclanché and Marie Davy are chiefly in use, while those in favor in Germany are Meidinger's and Siemens & Halske's, both of which are modifications of the Daniell. In India the Minotto is used almost universally.

33. *Describe the principal batteries used in the United States, and state the purposes to which they are respectively applied.*

The gravity battery is so named because the two solutions, sulphate of zinc and sulphate of copper, are separated from each other by the difference in their respective weights, the saturated solution of copper being heavier than the zinc solution, when the latter is in its proper condition.

John Fuller, in 1853, was the first to suggest the gravity battery. Cromwell F. Varley patented several varieties of this battery, which have since been repatented by several other inventors.

In the Callaud form the gravity battery is, as shown in Figure 9, constructed as follows: On the bottom of a glass jar is laid a copper plate, having two vertical plates attached in the form of a cross. This projects about three or four inches above the bottom of the jar.

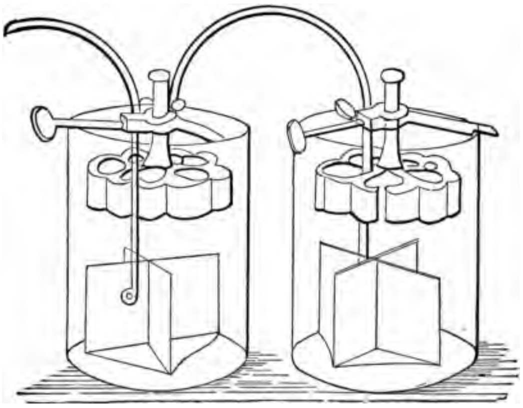


Fig. 9.

To this copper is connected an insulated wire, which is extended up through the liquid and forms the connecting link, to be fastened to the zinc of the next cell. On the copper plate is placed a layer of sulphate of copper. The zinc plate is then hung on a brass frame near the top of the cell, and the jar is charged with water or with a weak solution of sulphate of zinc.

The chemical action of this battery is the same as that of the Daniell: the zinc is oxidized by the oxygen of the water; the oxide of zinc combines with the acid set free from the sulphate of copper and forms sulphate of zinc, which remains dissolved, while the oxide of copper previously combined with the acid is reduced, by the action of the hydrogen of the water, to metallic copper, and is deposited on the copper plate. This battery is much used in telegraphy, having to a great extent superseded the Grove. It has also come into use for local circuits, to operate sounders and registers, and in furnishing motive power for signalling purposes on short telephone lines.

The Grove battery was until the last eight years almost universally employed as a main battery for the American telegraphs, but is now rapidly being pushed aside by the more economical Callaud. The Grove cell consists simply of a plate of zinc, as the positive plate, in dilute sulphuric acid, surrounding a porous cell in which is a plate of platinum immersed in concentrated nitric acid.

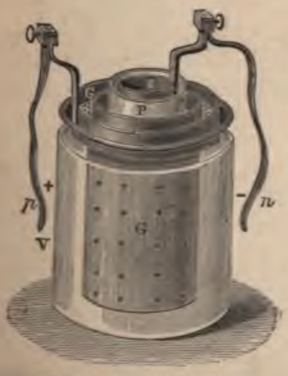


Fig. 10.—Daniell's Battery.

The Daniell, which is the original sulphate-of-copper battery and the forerunner of every type of gravity battery, is to some extent employed in electro-deposition, gilding, and silvering, as been much used as a local battery in tele- fices. It is shown in Figure 10 and consists of a jar containing a cylinder of zinc, G, and a porous cup, P, containing a plate of copper, X. The porous cup is placed inside the zinc and filled with dilute sulphuric-acid, with salt water, or with pure water. This construction admits of considerable variety. If desired the zinc may be placed in the porous cup and the copper in the outside vessel. The solutions would then also have to be changed so that the copper would always surround the copper. It is unnecessary to describe the action of the Daniell cell, as it is precisely the same as that of the Callaud, which has already been considered.

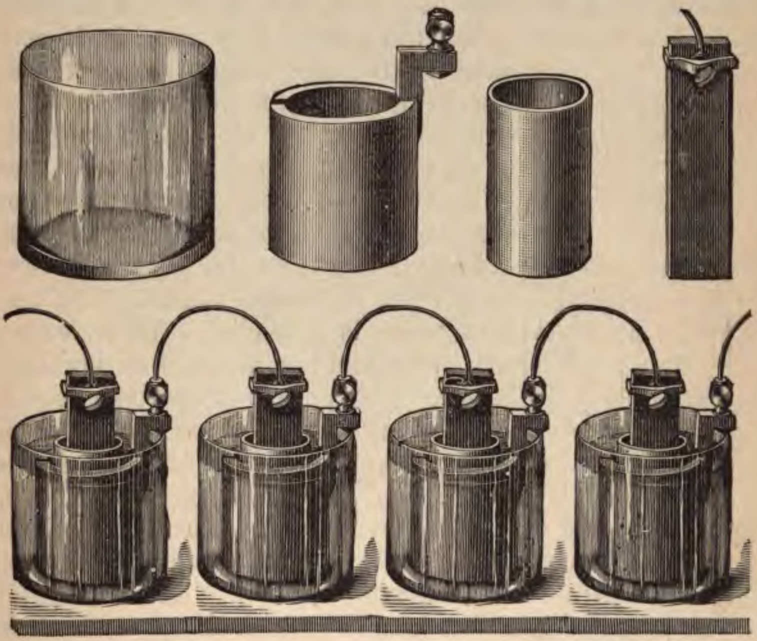


Fig. 11.—Chromic Acid Battery.

The chromic-acid battery, often in this country called the *carbon*, and occasionally the *electro poion* battery, has been much used for telegraph lines, and is at the present day largely employed for printing telegraphs, also for open-circuit work, such as burglar-alarms and domestic bell ringing. A cylinder of zinc is placed in a glass jar, a porous cup inside the zinc, and a plate of carbon in the porous cup. The porous cup is filled with a solution of bichromate of potash, and the outer cell with dilute sulphuric acid. Its arrangement is shown in Figure 11.

The Leclanché battery, which in 1870 was scarcely known, is now extensively used throughout the country as an open-circuit battery. It is economical, requires little attendance, and since the introduction of the telephone its use has more than doubled. A zinc rod is the positive element, and a mixture of crushed peroxide of manganese and broken carbon surrounding a carbon plate in a porous cup is the negative element. The carbon plate is provided with a leaden cap, to which is attached a binding-screw. The porous cup is then set in a glass jar, which is filled to about two-thirds its height with a solution of sal-ammoniac. This battery is well suited for electric bells, for signalling on telephone lines, and for Blake microphonic transmitters. It will keep in good order for months with very little attention.

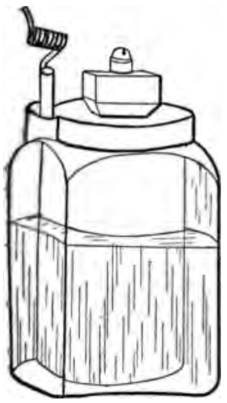


Fig. 12.

A modified Leclanché cell, in which the porous cell is dispensed with, is at present a very popular form, and is much used in connection with transmitting telephones. It was patented in 1875; and the depolarizer, instead of being packed round the carbon plate in a porous cup, is formed into a mass composed of equal proportions of peroxide of manganese and granulated carbon, held together by the admixture of from five to ten per cent. of a resinous cement; the carbon plate is enclosed in this mass, and the conglomerate mass sub- ed to strong pressure in a hot mould.

zinc forms one pole and the compound forms the other. Both are fitted with binding-screws and immersed in a sal-ammoniac solution.

This form is shown in Figure 13.

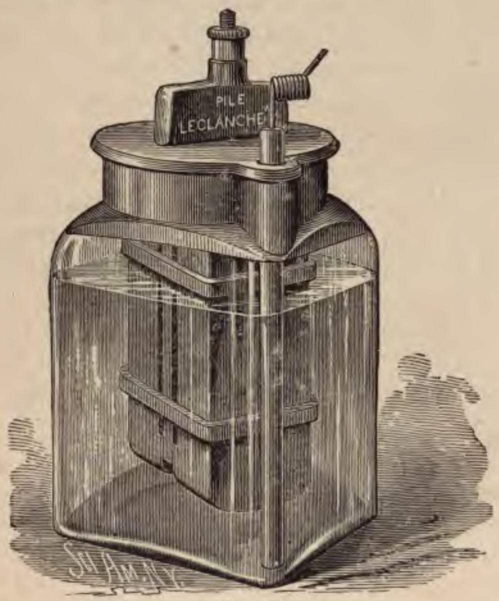


Fig. 13.

34. *What is meant by the "poles" of a battery?*

The wires, binding-screws, or terminals of each of the plates of a battery are called the poles. Their names are always opposite to those of the plates they lead from. Much confusion has existed in the minds of many persons with reference to these terms—the positive and negative *poles* of a battery, and the positive and negative *plates* of a battery. This, however, may be dissipated by observing that the term plate, metal, or element is applied to that part of the plate which is in the liquid, and the term pole to that part of the plate which is out of the liquid and which is attached to the conducting wire. The term "positive" is intended to signify that from whence the current of electricity proceeds, while the "negative" signifies that which the current enters. Now, the electrical action commences at the surface of the more oxidizable metal, which is usually zinc; therefore we call the zinc the positive plate. The positive electricity passes through the liquid, and is received and collected by the other plate, generally copper or carbon, which is hence called the negative plate. It passes from the end of that plate and out at the continuing wire, which by the same rule is called the positive pole; it then passes through the wire to the top of the plate from whence it originally started, which is consequently called the negative pole. It will, then, be understood that each plate of a battery has opposite terms applied to it.

In a zinc and copper battery the zinc is the positive plate, but the wire leading from it is the negative pole, while the copper is the *negative plate*, but the wire proceeding from it the *positive pole.*

35. *What is the signification of the terms "electrode," "electrolysis," and "electrolyte," which are frequently found in works on electricity?*

They are terms proposed by the late Professor Faraday, and have been used by electricians in various ways. The poles, or plates, leading a current into and out of a battery were called by him *electrodes*—that is, ways or paths of electricity, from the Greek words *electron* and *odos*. An *electrolyte* is a compound decomposable by the electric force, and the term *electrolysis* means the act of such decomposition.

36. *Give some simple directions for the care of batteries.*

The Daniell, gravity, Grove, and Leclanché batteries, being types of all the principal batteries in use, will alone be noticed here.

The Daniell Battery.—Use the best quality of copper sulphate procurable. Never use powdered sulphate, as it soon cakes and then dissolves too slowly to be of much use. Never use porous cups after they are cracked or any way damaged, or let the zinc touch the porous cup. If the zinc is used inside the porous cup, let it be suspended, so that it will not touch the bottom of the cup.

The zinc solution is at its best when it is half saturated. When it is stronger than that point of saturation, a portion should be drawn off and the cell filled up with water. At least once in two months a Daniell battery should be thoroughly cleaned, the plates scraped, and any copper found attached to the porous cup scraped off. The copper solution, if clean, may all be restored, but half the zinc solution will usually be sufficient.

The following hints may be given on the maintenance of the gravity battery:

After setting up, if the battery is weak connect the poles by a wire for a day or two; this will tend to separate the solutions and to concentrate the zinc sulphate solution. Keep the level of the water at least a quarter of an inch above the zinc. Avoid shaking the solutions. Keep the line between the copper and zinc solutions as sharp as possible.

If the blue is too low draw off a little of the upper solution with a syringe, and replace it with pure water; then leave the battery circuit open when not being used.

If the blue gets too high put the battery on short circuit when not in use.

If a froth generates on the surface remove it with a piece of wood or a brush.

If the zincs become very dirty take them out, scrape and wash them.

Jars should never touch each other. Shelves should not be allowed to become dirty. Generally speaking, if the blue rises too high the resistance in the circuit is too great for the battery.

Be sure that the covering of the insulated wire leading up from the copper plate is perfect; and in setting up a battery never use old material, unless it is in every respect good.

The Grove Battery.—The zincs of this and all other acid batteries should be kept well amalgamated in order to prevent local action. Grove batteries should be taken apart every night; one-tenth of fresh nitric acid should be added every morning, and the dilute sulphuric acid renewed twice a week.

Use great care in handling the acids, as they are very corrosive. Place the zincs every night in water weakly acidulated with sulphuric acid.

The Leclanché Battery.—Never let the outside solution rise above the shoulder of the jar. When setting up the battery pour a little water in the porous cup. The sal-ammoniac solution should be saturated, but too much sal-ammoniac ought not to be put into the jar at once, as it is apt to cake instead of dissolving. When the solution becomes too weak, crystals of oxychloride of zinc form on the zinc and weaken the action of the battery.

Watch the connecting wires carefully, as they are liable to be eaten through by the free ammonia generated in the battery. If the battery is weak, and no cause is apparent, test each cell separately, and, when the defective cell is found and examined, probably a salt of lead will be found between the lead cap and the carbon plate, partially insulating it. Renew the water in the outside vessel when necessary, at the same time adding a little sal-ammoniac.

If by accident the Leclanché cell be left on closed circuit and run down, its strength may be to a certain extent renewed by soaking the porous cups in water or dilute muriatic acid and giving the battery a considerable rest.

Rolled zinc should be used in preference to cast, as it is purer and more economical in the end.

The following hints are applicable to all batteries:

Insulate each cell perfectly, and keep the shelves on which they stand clean and dry. Keep all points of contact and all connections clean and bright. No leakage or creeping of liquids from the cells should be allowed, and as soon as any such thing shows itself it should be wiped away with a damp cloth. To prevent such action the edges of the outside vessel should be dipped in melted paraffine. The temperature of a battery room should not be too warm, or the liquids will evaporate; nor too cool, or they will lose power. Solutions should always be renewed before they are exhausted, and the batteries periodically examined, so that any defect will be located and removed before causing any radical trouble. Every connection must be made tight and kept free from oxide.

37. *How is the presence of iron in sulphate of copper detected?*

The suspected crystals must be dissolved in water, and liquid ammonia added to the solution. This will at first precipitate both copper and iron, and the solution will appear very cloudy. More ammonia is then to be added, when the copper will be redissolved, forming a bright blue solution, and the iron, if present, will fall to the bottom in the form of a brown powder.

CHAPTER III.

THERMO-ELECTRICITY.

38. *What is thermo-electricity ?*

Thermo-electricity is the name given to that branch of the science of electricity which relates to the production of electric currents by the agency of heat.

The term literally means heat-derived electricity.

Professor Seebeck, of Berlin, in 1823 discovered that if two bars of any two metals, especially bismuth and antimony, be soldered together at one end, and have their other ends connected with one another by a wire, so as to form a complete circuit, on the application of heat to the point where the metals are soldered a portion of the applied heat is absorbed and disappears, and an electric current is developed in its stead.

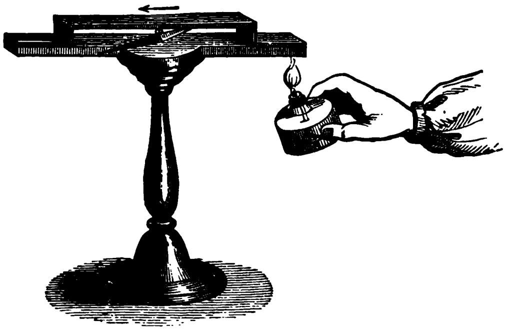


Fig. 14.—Electricity produced by Heat.

All metals, and many other conductors of electricity, are capable of producing thermo-electric currents, and they are all classed either as thermo-electro-positive or thermo-electro-negative bodies. The former class com-ises those conductors in which the current proceeds the colder to the warmer portion ; and the latter includes those in which the current proceeds in the opposite direction.

Bismuth may be regarded as the representative of the former class, and antimony as that of the latter. In experiments in this science, therefore, these metals are most frequently used. For example: We take a bar of bismuth, and solder or braze one end of it to one end of a bar of antimony, then attach a galvanometer by wires to the free ends of the two bars, so that the circuit is completed from the bismuth to the antimony by soldering; then from the other end of the antimony to one terminal of the galvanometer, and from the other terminal of the galvanometer to the free end of the bismuth. If we then heat the junction of the two bars we shall see the needle deflect, the current proceeding from the bismuth through the heated point to the antimony, thence through the galvanometer and back to the bismuth. Some metals when thus united are found to produce a current in one direction when the junction is moderately heated, but when the heat is increased the direction of the current is reversed.

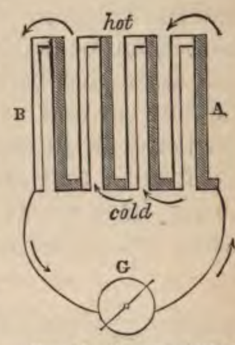
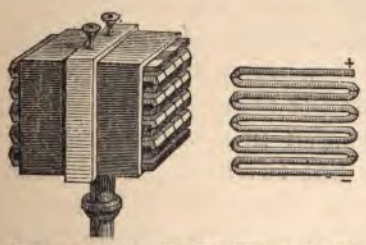


Fig. 15.—Thermo-electric Battery, with Galvanometer.

39. *What is a thermo-electric battery?*

When only one bar of each of the metals employed is used the arrangement is called a thermo-electric pair. A number of these thermo-electric pairs may be joined in series, just as a number of voltaic cells are joined together for the formation of a voltaic battery.



Figs. 16 and 17.—Nobili's Thermo-electric Battery.

When the pairs are so joined the entire series is called a *thermo-electric battery*, and its electro-motive force is equal to the sum of the electro-motive forces of all the pairs added together. To make such a battery, suppose we have six bars of bismuth and the same number of antimony, each bar being three inches long, three-quarters of an inch wide, and one-fourth of an inch thick. Arrange them alternately, so that if the first bar is bismuth the last will be antimony. The bars must then be soldered together at each end, the second, antimony, being, for instance, at one end soldered to the first bar and at the other end soldered to the third; the third, in its turn, having its other end soldered to the fourth, and so on. The two terminal bars will, of course, have one end unattached. These free ends represent the poles of the battery. To set the battery in operation all the junctions on one side must be heated, while all those on the other side must be kept cold. While the arrangement described represents the principle of the thermo-battery there are many varieties, modifications, and improvements. One of the first thermo-batteries was invented by Melloni in 1834. He made what he called a thermo-multiplier. It consisted of about fifty little bars of antimony and bismuth enclosed in a brass cylinder, the whole arrangement being but two and a half inches long and about half an inch in diameter. The terminal bars were connected by wires to a delicate galvanometer. This contrivance was so sensitive to slight changes in temperature that when the hand was brought ar to one end of the instrument the current generated sufficient to move the needle several degrees. Two

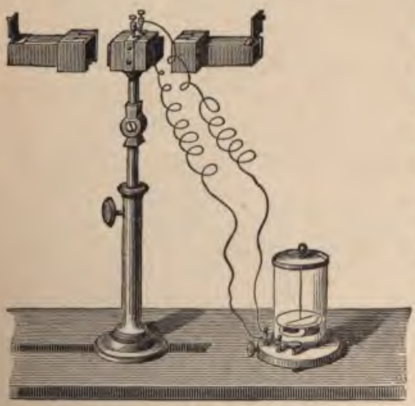


Fig. 18.—The Thermo-electric Multiplier for Measuring Heat.

of the most efficient thermo-electric batteries are those of Nöe, of Vienna, and Clamond, of Paris; the former being more speedily excited and giving a powerful current, and the latter being very strongly constructed. To sum up: A thermo-electric battery may be briefly defined as a device which transforms heat into electricity.

40. *Has the thermo-electric battery ever been employed for practical purposes?*

Yes, it has been applied to several purposes. Melloni, at a very early date, used the thermo-pile, previously described as having been constructed by him, to measure small differences in temperature. Clamond's battery has been quite extensively experimented with in England for working telegraph circuits. It was expected that the thermo-electric pile, in Clamond's improved form, would, on account of its low resistance, be useful as a universal battery—that is, one from which many circuits are worked; and at one time five thermo-batteries were used to work no less than ninety separate circuits from the London post-office. Each of these circuits was less than one hundred miles in length. All the thermo-batteries, however, ultimately failed by the burning out of the insulating material between the several layers of bars. This is probably not a fault which will prevent the thermo-pile from being eventually used.

But the most important application of the thermo-electric battery has hitherto been to furnish a current for the electro-deposition of metals, or, to use more familiar terms, for electro-plating. It was first so used in 1843 by Moses Poole, and patented, but did not then come into general use. Thermo-electricity has, however, been more or less employed since that time for plating, and, since the invention of Clamond, has done efficient work. Clamond's thermo-electric battery is now in use in various plating establishments in Birmingham, London, and Sheffield, and it is said that a machine of one hundred bars, with a consumption of eight to nine feet of gas, deposits an ounce of silver per hour.

These batteries have experienced such important improvements of late years that it is believed they will soon be utilized with great advantage.

CHAPTER IV.

EARTH-CURRENTS AND EARTH-BATTERIES.

41. *What are earth-currents?*

They are currents which are always flowing through telegraphic lines, and which depend for their existence on a difference of potential between the two points of the earth at which the line is terminated. They are, therefore, currents flowing from one part of the earth to another, which, being of course subject to the ordinary laws of electricity, and finding another path open to them at the ground-plate where they enter, divide there, part of the current taking the wire route to the distant point, the other part taking the route through the earth.

They vary in strength at different periods in the day and year, and sometimes are so strong as to render the working of a line difficult. They are then called electric storms.

Sometimes they flow in one direction, sometimes in the other, and in any case are very unwelcome visitors in telegraph lines.

They are particularly frequent on long cables, and endanger the safety of the cable. They also render testing with the galvanometer very uncertain and incorrect.

42. *How may the effects of earth-currents on telegraph lines be obviated?*

On ordinary telegraph lines this may be done in two ways: The first mode may be adopted when two wires run parallel to each other; it consists in abandoning the use of the ground-wires at the terminal offices, and looping the wires, so as to form a metallic circuit. In practice, if the wires are looped together at but one end the result is satisfactory.

The second method may be used where there are *not* two wires parallel to each other, and is effected by removing the ground-wire at one end of the line and lengthening the circuit by connecting another line running in another direction to it, so that if a straight line were drawn connecting the two end offices it would be out of the direction of the earth-current prevailing at the time.

In the case of submarine cables of considerable length the same result is effected by the use of condensers, which are interposed between the ends of the cable and the ground.

43. *Are there any other currents which appear on telegraph lines without apparent cause?*

Yes. If the earth-plates of a circuit are of different metals a permanent current will be set up, varying in strength according to the metals used. For example, if a copper plate be buried in the earth at one end of the line, and a zinc plate at the other, the current will be comparatively powerful. If one earth-plate be of lead and the other of iron, the current will not be as strong as that developed by the copper and zinc, but it will still be quite perceptible.

This may readily occur, and to the inexperienced electrician sometimes proves very puzzling. If, for instance, the wire be grounded on an iron gas-pipe at one end of the line and on a lead water-pipe at the other, and a current appears, as under the circumstances it surely will, it needs some experience to determine its origin. When suspected one ground or the other must be changed until no current passes.

This current has been utilized under the name of the earth-battery current. It was used by Gauss in Germany at an early date, was subsequently employed by Bain to work electric clocks, and in 1846 was used by Steinheil on a Bavarian telegraph line twenty miles long. For telegraphs, however, it has not attained any remarkable degree of success.

CHAPTER V.

MAGNETISM—ELECTRO-MAGNETISM AND ELECTRO-MAGNETS.

44. *What is magnetism?*

It is the name given to the science which treats of the peculiar properties of attraction, repulsion, polarity, and the development of magnetism in other magnetic bodies by induction, which are possessed, under certain conditions, by iron and some of its compounds, and in inferior degree by nickel. The metals cobalt, chromium, and manganese also possess magnetic properties to a limited extent.

The term is also employed to denote the cause of magnetic phenomena. The name is generally supposed to be derived from Magnesia, a place in Asia Minor, where the natural magnet was originally found by the Greeks.

The existence of magnetism is noticed in very ancient Chinese, Greek, and Roman manuscripts.

45. *What is a magnet?*

A body which exhibits magnetic properties is called a magnet. The name is usually confined to the ferrous substances mentioned above (44); but all conductors of electricity are capable of showing similar effects while conveying a current.

46. *What is a natural magnet?*

The natural magnet, often also called the loadstone, is an ore of iron, called by chemists *ferrosoferric oxide.*

It is known by the symbol $F^3 O^4$, and is by mineralogists termed *magnetite.* It is generally met with in small pieces, but sometimes occurs of quite a large size.

It is composed of about seventy-three parts iron and twenty-seven oxygen. First found in Magnesia, in Asia, it has since been procured from many other places, and at the present time the most powerful natural magnets are found in Siberia and in the Harz Mountains of Germany.

The natural magnet has been known in almost every country from the earliest ages, and in nearly every language the name given to it is based on its supposed partiality for iron. The English name loadstone is derived from the Saxon word *lœdan* (to lead), a name suggested by observation of its directive power.

The attractive force of the natural magnet is not great in proportion to that exhibited by artificial magnets, as it is very seldom that a piece is met with that will sustain its own weight.

47. *What is an artificial magnet?*

It is a body possessing all the properties of the natural magnet, these properties having been imparted to it by artificial means. If a bar of hard steel is repeatedly rubbed from end to end by a magnet, the steel receives all the magnetic properties. Or if such a bar is placed within a helix of insulated wire, and a current of electricity passed through the helix, the bar becomes magnetic. A piece of steel thus acted upon is an *artificial magnet.*

The property which magnets have of imparting magnetism to steel is extremely valuable, as steel can be easily shaped into any required form, and utilized in many ways and for many purposes that a natural magnet could not be applied to.

48. *What are the characteristic properties of magnets?*

First, *Attraction.* This property resides principally in two opposite points. These points are called poles. When either pole of a magnet is brought near to a piece of iron a *mutual* attraction takes place between them. The reason is that the iron also becomes magnetized by its proximity to the magnet, the part which is nearest to either pole of the magnet acquiring an opposite polar ity to it, causing the iron to attract the magnet with a force equal to that with which the magnet attracts the iron. Thus it will be seen that the attraction which a magnet apparently has for iron is really an attraction for the opposite pole of another magnet, as graphically shown in Figure 19.

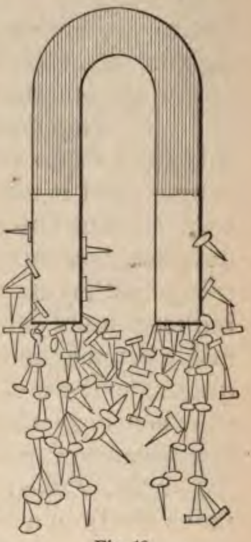


Fig. 19.

Second, *Repulsion.* This is seen in the action of two magnets upon each other. If two magnets are suspended so that they can move freely in an horizontal plane, and their similar poles are placed close together, they will be observed to repel each other and turn round until their opposite poles are in juxtaposition. Or if, as in Figure 20, one of the magnets, *s n*, is suspended, and the second, N S, is brought close to it, the north pole of one being presented to the north pole of the other, a quick repulsion takes place; the same occurring also if two south poles are brought together.

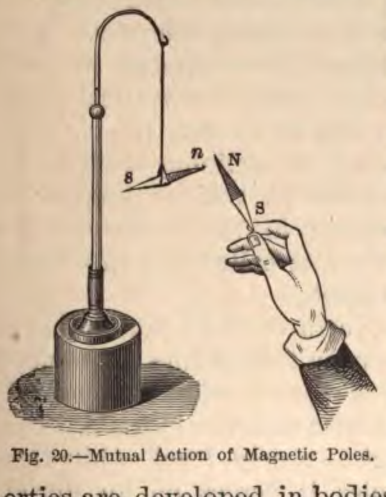


Fig. 20.—Mutual Action of Magnetic Poles.

Thus the two magnetisms in this have a resemblance to the two electricities: like poles repel; opposite poles attract.

Third, *The power of developing magnetism in iron or steel by induction.* Whenever magnetic properties are developed in bodies not previously possessed of them, the process is called magnetic induction; and for such development it is not necessary that the body shall be brought into actual contact with the magnet.

By bringing a magnet near to iron or steel the latter bodies are rendered magnetic by induction; are then capable of attracting iron, and themselves possess the power of communicating the properties to other pieces of iron. This is especially the case with soft iron, and it is only while the iron remains in the vicinity of the magnet that it retains these qualities.

As soon as the magnet is withdrawn, the iron loses its induced powers. With steel and hardened iron the case is different. When iron is hardened magnetism is induced more slowly, and is more slowly parted with; and when magnetism is induced in hardened steel it requires, as it were, to be rubbed in.

When once thoroughly magnetized the piece of steel is a permanent magnet.

Fourth, *Polarity*. If a magnet is suspended so as to move freely in a horizontal direction it will always come to rest with the same pole pointing to the north, as in Figure 21.

This property is called polarity, or directive force, and is familiarly illustrated by the ordinary compass. If the magnet is suspended so as to move freely in a vertical plane, it will be found to have the power of inclining itself to the horizon at various angles, according to the locality. This power is called the *dip* of the magnet.

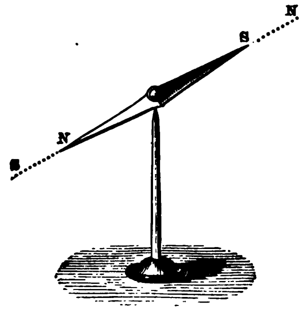


Fig. 21.—Directive Action of the Earth.

North of the equator the extremity that points to the north dips; south of the equator the other end dips. The dip varies with the latitude. Near equator the needle lies nearly level, while near north and south poles it verges on an upright

In the latitude of New York the angle of dip is about seventy degrees.

49. *What are the poles of a magnet?*

The extremities of a magnet, where its magnetic powers most clearly manifest themselves. In a bar magnet the poles are found very nearly at the ends. The earth is itself a magnet, and has north and south magnetic poles. The pole which in any magnet points to the north is called the *north pole*, and the other is called the *south pole*. Any two north poles repel each other, as do also any two south poles; but any north pole attracts any south pole, and *vice versa*.

The poles of the magnet are shown in Figure 22, in which iron filings are seen to accumulate at both ends of the bar, while the middle does not attract them at all.

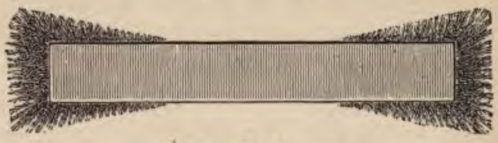


Fig. 22.—The Magnet.

Hence the directive power of the magnet. The north pole of the earth attracts the opposing pole of the magnet, which, strictly speaking, should therefore be called the south pole; but it has long been customary in English-speaking countries to call the pole pointing to the north the north pole, hence it would now tend to create confusion if the practice were changed.

If a magnet be broken in two each piece becomes a complete magnet, with north and south poles.

It has been found desirable for practical purposes to distinguish the two poles by marking one of them—usually the extremity which points northward—with a small file-cut. Another method is to color the north pole blue and the south pole red.

50. *What is a permanent magnet?*

As previously noticed, steel (which is a compound of iron with carbon), while it acquires magnetism with difficulty, retains its magnetism more or less permanently, after the withdrawal of the inducing magnet. This difficulty in the reception of magnetism, and the permanency with which, when once acquired by steel, it is retained, is called *coercive force.*

On account of the latter property a magnet formed of hard steel is called a permanent magnet.

Permanent magnets may be of any required form, but for general purposes only two styles are made—namely, *bar* and *horseshoe* magnets.

51. *Describe the bar, horseshoe, and compound magnets.*

A *bar magnet* is an artificial permanent magnet in the form of a straight bar. The magnetic needles used in telegraph instruments and compasses are delicate bar magnets.

A magnet which is bent in such a manner as to bring its two ends, or poles, near each other, so that they can be connected by a short, straight piece of iron, is called a *horseshoe magnet.* Magnets for general use are most frequently made in this form, because it is then easier to bring both poles into play upon the same object.

The short piece of iron spoken of as being used to connect the poles of a horseshoe magnet should be of soft iron. It is called an *armature*, or *keeper*, and when the magnet is not being used, the armature, to prevent the loss of power, should be constantly kept across its poles.

A *compound magnet* consists of two or more bar or horseshoe permanent magnets, placed side by side and fastened together, with their similar poles in contact.

They are arranged in this way for the purpose of increasing the magnetic power.

Although a compound magnet is stronger than any of its component magnets, it is very much weaker than the sum of the strengths of all the magnets, were they used separately. This is because the similar poles of all of them, being laid close to one another, have a tendency to react on each other, and, to a certain extent, induce an opposite polarity in the contiguous magnets.

52. *Describe the process of magnetizing steel for the formation of permanent magnets.*

There are several different methods of magnetizing steel bars, needles, and horseshoes, among which may be noted the following as the most important and the most generally used. Small needles can be magnetized by merely placing them across the poles of a permanent magnet for a short time. One of the simplest ways to magnetize a steel bar is to place the *middle* of the bar on one of the poles of a strong bar or horseshoe magnet, and draw one end of it over the pole a number of times, never failing to draw it from the middle to the end ; then turn the bar end for end and repeat the process, drawing the other end over the other pole of the permanent magnet. The end that has been drawn over the north pole of the permanent magnet will possess south polarity, and the other will possess north polarity.

A horseshoe can be magnetized by drawing it over the two poles of a permanent or electro magnet in such a way that both halves of the horseshoe pass at the same time over the poles to which they are applied. If it is thick it should be turned over, and the process repeated on the opposite side.

But of all the modes practised the most efficient is the use of the electric current. A helix is prepared, consisting of a number of layers of insulated wire. It has a small central opening, and when a steel bar is placed inside the opening, and a strong current passed through the helix, the bar is strongly magnetized.

53. *What is the meaning of the term "magnetic field"?*

The presence of a magnet always modifies in some way its immediate neighborhood, so that pieces of iron and steel brought into the proximity of the magnet acquire magnetic properties by induction ; and any other *magnet* placed there shows at once that it experiences a peculiar force.

This locality immediately surrounding the magnet is called the *magnetic field*, and the term literally means the extent of space surrounding the poles of a magnet in which the magnetic forces may be recognized.

54. *What is diamagnetism?*

In 1845 Faraday demonstrated the magnetic condition of all matter, and showed that all bodies divided themselves into great classes—the one attracted, the other repelled—by the poles of a magnet. As the force producing the former result is called magnetism, he gave to the force causing the repulsion the name *diamagnetism*, or cross-magnetism. And any substance which, when delicately suspended between the poles of a magnet, instead of settling across from pole to pole, arranges itself transversely to that position, so that it points in the same direction as the magnet and is repelled by both poles alike, is called a *diamagnetic body*. The bodies which most strongly exhibit this force are bismuth, antimony, and zinc. But the force of diamagnetism is, at its best, much feebler than that of ordinary magnetism, as bismuth, which is of all substances the most strongly repelled, is still repulsed with a force so much less than that exerted in the attraction of iron as to bear no comparison to it.

55. *What is the nature of the relation between electricity and magnetism, and by whom was this relation discovered?*

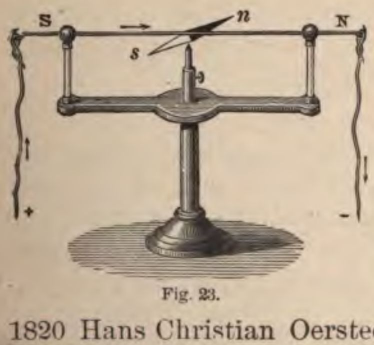


Fig. 23.

The discovery of the relationship between electricity and magnetism was an object eagerly desired and sought for by the electricians and scientists of the last century, but for such a protracted period without result that it was doubted, and by some even denied, that any such relationship existed. But in the year 1820 Hans Christian Oersted, professor of natural philosophy at Copenhagen, announced his discovery that if a wire conveying an electric current be placed horizontally above a magnetic needle, and parallel to it, the needle is deflected, as represented in Figure 23, and tends to place itself at right angles with the conducting wire, the end of the magnet nearest the positive pole of the battery deflecting eastward.

If the conducting wire be similarly placed *under* the needle all the effects are the same, except that they are in an opposite direction.

This relationship, described in plain language, consists literally in the fact that a wire electrified by a constant source or stream of electricity becomes practically a magnet (or, to speak more correctly, a straight current produces in a wire a magnetic field, in which the lines of force are circles concentric with the wire), and disturbs the magnetic field of the earth's magnetism, consequently tending to deflect a magnetic needle, pivoted within the sphere of its influence, from its position pointing north and south.

From the foregoing facts, when announced by Oersted, Ampère, of France, made the deduction that "magnetism is the circulation of currents of electricity at right angles to the axis joining the poles of the magnet." Arago (also a French scientist) shortly after showed that every conductor of electricity, while conveying a current, becomes possessed of magnetic powers, and in the same year discovered that current electricity would magnetize small pieces of iron and steel; and he accomplished this by placing them in a glass tube and winding a wire, which connected the two poles of the battery, round the tube. Sir Humphry Davy, of England, likewise in 1820 found that sewing-needles could be magnetized by merely rubbing them across a wire conveying electricity. From this time electrical discovery has been rapid and progressive.

The two forces are so intimately connected that by many scientists they are considered to be only different manifestations of the same agency, the motion of a magnet always producing electricity, and the transfer of electricity as uniformly producing magnetism.

56. *What is electro-magnetism?*

It is that department of electrical science which relates to the development of magnetism and the deflection of magnetic needles by means of electrical currents.

57. *What is an electro-magnet?*

A helix of wire conveying a current of electricity has magnetic properties. If such a spiral be made of insulated wire and wound on a bar of soft iron the iron becomes magnetized and its force is added to that of the coil. The combination of the coil and the iron together is called an *electro-magnet*. Electro-magnets may be made of any form, but the most common forms are the *bar*, in which the poles are as far apart as possible, and the *horseshoe*, in which the poles are as close together as possible.

For practical purposes they are made by winding covered copper wire on two bobbins or spools, *a a'*, passing soft-iron cores, *c c'*, through them, fixing the two soft-iron cores on a connecting piece or yoke, *b*, also of soft iron, and connecting the two spirals together in such a manner that if the cores were straightened out into one bar the wire would be coiled in the same direction from one end to the other.

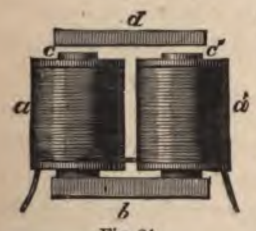


Fig. 24.

The ends of the cores are called the *poles* of the electro-magnet.

An electro-magnet has, as long as the current flows in the coils, all the properties of a permanent magnet, and can be made to possess much greater power than a permanent magnet of the same size. The magnetic ce developed in any electro-magnet is dependent on the strength of current, the number of turns the wire takes round the core, and the size of the iron core itself.

The first electro-magnet was made in 1825 by Sturgeon, but a practical and useful one was not produced until 1830, when Professor Henry constructed the first magnetic spool or bobbin ever produced, by winding insulated wire round a soft-iron core, and by so doing exalted the power of the electro-magnet in an astonishing degree.

58. *What is residual magnetism?*

We have seen that when a piece of soft iron is brought near to a magnet it becomes magnetized by induction, and that when removed from the influence of the magnet it loses all trace of its induced magnetism. This is also the case with electro-magnets. When a current is conveyed through the coil of the electro-magnet the soft-iron core is strongly magnetized; and when the circuit is broken, or from any cause the current ceases to flow, demagnetization instantly takes place. It is this property that makes the electro-magnet so valuable and so universally useful. It must be observed, however, that this complete demagnetization is dependent on the quality and softness of the iron. If it is not very soft and pure, or, in the case of an electro-magnet, if the armature is allowed to touch the poles, a certain amount of magnetism remains in the iron, and is called *residual magnetism*. Hence the iron used should be of the softest and purest kind, old Swedish iron being preferable.

59. *In making calculations on the strength of electro-magnets is the resistance of the battery to be taken into consideration?*

In short circuits, where the resistance is proportionately large to the resistance of the rest of the circuit, it should be. For example, in a local circuit of a Morse sounder there is practically no resistance outside of the sounder-coil, except the battery. It is obvious, then, that it *must* be considered and the coil made equal to it. But when the battery of a very long external circuit is in question it is not necessary to include the resistance of the battery with that of the circuit, because, though large, it is yet, in proportion to the rest of the circuit, very small, and to simplify the calculation it is usually ignored.

60. *Has the length of the iron core any effect on the working of an electro-magnet?*

Yes. Electro-magnets with short cores charge and discharge more rapidly than those with long ones. Advantage of this fact has been taken in telegraphy, and all the later forms of relay have short cores. A magnet also works quicker when charged by a battery of many cells than when few are used. When strength rather than speed of action is required it is well to employ magnets with long cores, because the convolutions of wire can then be increased in number without increasing their distance from the core, by adding a great number of layers of wire.

61. *What proportion should the resistance of an electro-magnet bear to the resistance of the other component parts of the circuit?*

It is one of the laws of electro-magnetism that with any given battery the greatest magnetic force is obtained when the resistance of the coils of the electro-magnet or magnets is equal to the resistance of the other portions of the circuit—that is, of the batteries and conducting wires. This law holds good practically on short and local circuits; but on long telegraphic circuits it is only applicable when they are perfectly insulated. It is, therefore, usual in telegraphic practice to make the total resistance of the electro-magnets considerably less than that of the line, when in good order, so that in bad weather the best results may be obtained.

To illustrate: It is required to ring a bell over a copper wire one hundred feet long, with two cells of Leclanché battery. What should be the resistance of the bell-magnet to obtain the greatest magnetic power? The Leclanché cell has an internal resistance of about one ohm; therefore two cells would have a resistance of two ohms, and in this case the conductor, on account of its shortness, may be ignored. The resistance of the bell-magnet need be only two ohms to obtain the best result. The consideration of wire comes in here. Although we have decided that the resistance of the coils should be two ohms, it is still possible to err in the size of wire employed; therefore after ascertaining, by the relative resistances of the circuit and the rule already given, what the resistance of the electro-magnet should be, we must take care not to use wire that is too fine, or we shall reach the required resistance before the core is sufficiently covered to give much magnetic effect, as with very fine wire it takes very few convolutions to give a resistance of two ohms.

It is essential not to use wire that is too coarse, as in that case we have to wind so many layers that, except in the first one or two layers, the convolutions are so far away from the core as to lose their influence on it. Wire should always be chosen, therefore, for winding electro-magnets that will reach the required resistance before the last convolution attains a distance of half an inch from the core. Between half an inch and three-eighths from the core is the best distance for the last layer of wire.

We will now suppose a line half a mile long, built of No. 9 iron wire, with two bell-magnets in circuit, and a battery of ten cells. The battery resistance is ten ohms, the line resistance about eight ohms; total resistance of line and battery is, then, eighteen ohms. The sum of the electro-magnets should then, likewise, be eighteen ohms, or nine ohms each, to obtain the greatest magnetizing power from the given battery of ten cells.

62. *In constructing an electro-magnet for a very short circuit what kind of wire should be used, and why?*

We have seen that the resistance of the electro-magnet coil should be equal to that of the other portions of the circuit. It is, therefore, apparent that to accomplish this in a very short circuit it is necessary to employ a comparatively short, coarse wire—short, because even a very small addition would increase the resistance of the circuit out of all proportion; thick, because the current is not greatly enfeebled by its use, while the number of convolutions it allows of are sufficient to effect a strong magnetization. In short, we use a comparatively thick wire because it is necessary to get the greatest magnetic effect without the weakening of the current consequent on the use of a thin wire, which necessarily is of high resistance.

63. *How should an electro-magnet be made for a very long circuit, or a circuit of very high resistance, and why?*

For a long circuit, such as that of a telegraph line, or a circuit which has a high resistance outside of the coil—for instance, in the battery—the magnet must be wound with a very fine, small wire of great length, which will allow of a great number of convolutions being wound over the core without exceeding the distance at which they cease to increase its magnetism. The reason of this is that in a very long circuit, like a telegraph line, or in a circuit of very high resistance, the current is necessarily very weak and feeble, even though the battery be composed of a large number of cells. The coil is, therefore, made of fine wire, so that a great many convolutions can be used, each one adding its own influence to the combined magnetic effect, while its own resistance (which, considered by itself, is great) is yet so small in proportion to the entire circuit that it does not decrease the strength to any great extent.

The rule relating to the proper proportion of the electro-magnet to the circuit holds good in this case. For example, we have a line, two hundred miles long, of

No. 9 wire, and a battery of eighty Callaud cells. We are to have five relays. What should be the resistance of each of those relays?

"We call the line-wire resistance 16 ohms per mile; then for 200 miles the line resistance will be 3,200 ohms. Calling the battery resistance 3 ohms per cell, the resistance of the entire battery will be 240 ohms, giving as the total resistance of line and battery 3,440 ohms. Then, following the rule already given, we must make the total resistance of the electro-magnets 3,440 ohms also. This divided by 5, for the number of magnets, gives as the resistance of each magnet 688 ohms. In practice, however, as has already been observed, it is well to keep the magnet resistance less than that of the line and battery, to allow for variations in resistance due to weather. Moreover, in this country, for uniformity, the resistance of the majority of relays used is made very much the same for comparatively long and short circuits.

"The condensed reason, then, why we use fine wire—and a great deal of it—for circuits of high resistance, is that the high resistance of the circuit greatly enfeebles the current, and we must use fine wire to make the best of the remaining strength of the current by a greatly-increased number of convolutions."

64. *When we require an electro-magnet for long lines, or for circuits of great resistance, why do we call for one of high resistance? Is high resistance advantageous?*

No. Resistance, considered by itself, is a positive disadvantage, because every additional unit of resistance added to the circuit tends to further enfeeble the current. But, as already stated, to make the most of the existing current we require many turns of wire, and the resistance is a necessary but unwelcome adjunct. If we could obtain the convolutions without the resistance it would be so much the better, but that is impossible; and it has been found convenient to designate magnets intended to work on long lines as high-resistance magnets—not because it is *in virtue* of their high resistance that they work better, but simply because they necessarily have a high resistance, and to denominate them as such is an easy way to distinguish them.

CHAPTER VI.

MAGNETO-ELECTRICITY, AND MAGNETO AND DYNAMO-ELECTRIC MACHINES.

65. *What is magneto-electricity?*

It is a name which has been applied to electric currents which are developed by the relative movements of magnets and electric conductors. The term refers simply to the mode of generation, and there is no difference in kind or character between such currents and electric currents developed any other way. For example, if a magnet and a coil of insulated wire are caused to alternately approach and recede from each other rapidly, momentary currents are induced in the coil, which are alternately opposed to each other in direction. The process of developing magneto-electricity, as already stated (see answer 18), is called *magneto-electric induction.*

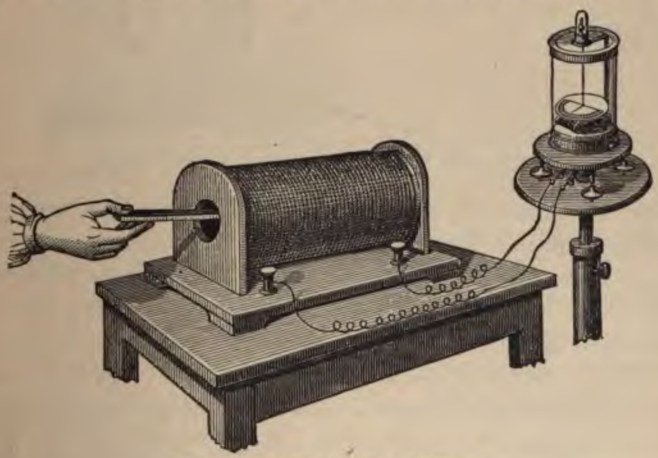


Fig. 25.—Magneto-Electric Induction.

It is one of Faraday's most important discoveries. While experimenting in the year 1831, he ascertained that by inserting the end of a permanent magnet into the middle of a coil of wire to which no battery was attached a current of electricity was produced, whose direction depended upon the pole of the magnet inserted and the direction in which the coil was wound. By inserting the other end of the magnet a current in the opposite direction was produced.

In the same year he produced a spark, *a*, *b*, by pulling an armature, *s* (covered with a coil of insulated wire, *n*), from the poles, N, S, of a magnet (Figure 26), and also obtained magneto-electric currents by rotating a copper plate between the poles of a magnet, and by sliding a coil of insulated copper wire upon a bar magnet. We see, therefore, that by the mere motion of a magnet in near proximity to a conductor, or of a conductor in the immediate vicinity of a magnet, without any battery, dynamic electricity may be produced. In the next year, 1832, the first magneto-machine was invented, and electricity generated in this manner is now one of the most important agents in the useful arts, and is for many purposes to be preferred to that produced by voltaic batteries.

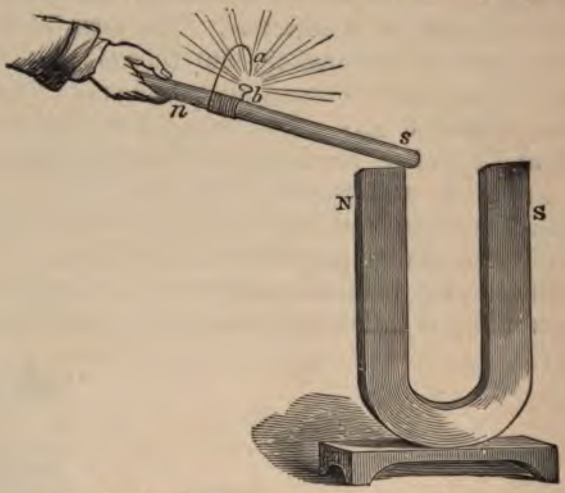


Fig. 26.—The Electric Spark obtained from a Magnet.

66. *What are the principal applications of magneto-electricity?*

It has been extensively applied in ways too numerous to recapitulate. The following are, however, a few of its most important applications:

Magneto-currents generated by small machines are frequently used for medical purposes, and have also been much employed in the experimental room and laboratory for chemical and physiological reactions.

It is now almost universally used in the production of the electric light, and was first employed for that object by F. H. Holmes, who showed a machine for the purpose in the International Exhibition of 1862, since which time whenever the electric light has been profitably used, its currents have been generated by magneto-machines.

For blasting, and the explosion of mines and submarine charges, it has proved a very valuable agent, Professor Wheatstone having devised an ingenious apparatus for the ignition of fuses. It has the power of igniting from two to twenty-five fuses simultaneously.

The application of magneto-electricity to electro-plating was an event of importance in the history of that art. It was first so applied in 1842, and the machine then introduced was used for many years, but has now been superseded by newer and more improved arrangements, such as the Gramme, Weston, or Siemens and Alteneck machines.

One of the most important applications of magneto-electricity is to telegraphy. Gauss and Weber, in 1833, moved their telegraph needle by magneto-electricity, which was the first employment of Faraday's discovery in such service.

Subsequently Steinheil in 1837, and Wheatstone in 1840, made great improvements in apparatus; and at the present time Wheatstone's alphabetical telegraph is almost exclusively employed on country lines in England, while the magneto-pointer telegraph of Siemens and Halske holds its own as a private-line instrument in Russia and Germany. In our own country the magneto-printers of G. L. Anders are well and favorably known.

The magneto-current has been more extensively employed during the last few years than ever before, owing to the extraordinary number of magneto-bells manufactured and introduced as telephone signals. The telephone itself is also an important application of magneto-electricity, which will be more fully considered hereafter.

A few years since an attempt was made by J. B. Fuller, of Brooklyn, N. Y., to work the Morse telegraph lines of the Western Union Telegraph Company by means of a dynamo electric machine. On account of the high speed necessary at that time to produce a uniform current this experiment was unsuccessful and was soon abandoned.

In 1880 Stephen D. Field, of New York, renewed the experiment with improved apparatus and with a different arrangement of circuits. He used three machines, two of which had their armature coils in the circuits to be operated, while the third machine served to energize the field magnets of the first two.

And at the present time dynamo-electric machines have at many of the main offices (not only of the Western Union Telegraph Co., but also of the Postal Telegraph Company and its allies) been substituted for batteries as sources of electricity, with extremely satisfactory results.

67. *Has the magneto-electric system of developing electricity any advantages over the voltaic-battery method? If so, describe some of them.*

For certain purposes it has decided advantages, some of which may be enumerated as follows :

On comparatively short telegraph lines, such as private and municipal telegraphs, it is far superior to the battery system, inasmuch as although the first cost of the machine is greater, there is practically no outlay for its management and maintenance, while the expense and annoyance inseparable from the maintenance of batteries are totally dispensed with.

It has also been ascertained, in the practical working of magneto-telegraphs, that they will work satisfactorily over a heavy escape that renders a line worked by batteries totally inoperative.

In the production of the electric light the magneto-machine presents great advantages on the score of economy and convenience. It has also been the most valuable agent in bringing the cost of the light within commercial requirements.

The chief objection to the use of the electric light was formerly the enormous expense necessarily contingent on the continued use of large voltaic batteries, and the consumption of zinc and other materials essential to keep them in good working order.

The introduction of the magneto-machine in 1862 by Holmes, and the successive improvements that have since been effected by Wilde, Siemens, Wheatstone, Ladd, Gramme, Weston, and others, have completely obviated this objection and made the electric light an ordinary illuminator, known and valued by many, instead of being, as formerly, a cabinet curiosity, only within the grasp of the professional electrician.

These machines have also, with excellent results, been applied to electro-plating and electrotyping, and for that service are now being universally preferred to batteries, with the same advantages as in their application to lighting. This application of magneto-electricity was first made in 1842 by J. S. Woolrich, who took out a patent for the use of a magneto-electric machine in electro-plating. The modern machines of Wilde, Gramme, Siemens and Alteneck, and Weston have, however, entirely superseded the Woolrich machine, and are now, in some of their multitudinous types, constantly used. The first Gramme machine used for this purpose ran five years without repairs or outlay, except the cost of oil for lubrication.

But since the general introduction of the telephone magneto-electricity has been extensively employed for signaling purposes. Merely mentioning the telephone itself, in which the magneto currents may be said to be involuntarily generated, it was early seen that some signal was necessary to attract the attention of the distant telephone operator; and the application, in a branch circuit, of the magneto-electric generative apparatus, in combination with the special polarized armature invented by Thomas A. Watson, answered the purpose so admirably that it is still used substantially in the same manner as at first.

Many thousands of these bells are now in use, and will be fully described in their place. The use of the magneto-bell for a signal has also the advantage of being able to ring over long or short lines indifferently, and in large offices the economy in maintenance, and the valuable space saved which would otherwise be devoted to large batteries, is such a consideration as to render the magneto system the only one now regarded as worth a second thought.

68. *What is a magneto-electric machine?*

A magneto-electric machine may briefly be defined as an apparatus whereby mechanical motion is by means of magnetism transformed into electricity. Such machines are made in many different forms, and the modifications of the machine are almost as numerous as are those of the voltaic battery. Nearly all may, however, be comprehended in three classes:

First. Those in which the working current is generated by the movement of coils of wire in the vicinity of permanent magnets.

Second. Those in which a comparatively small permanent magnet and armature are made to generate a current which is merely made use of to excite a very large electro-magnet. This is then used to induce a second current, which can be as much stronger than the first as the electro-magnet is more powerful than the permanent magnet.

Third. Those in which the small amount of residual magnetism always present in electro-magnets is utilized to generate a current, which is first used to increase the magnetism of its inducing magnet and thereby its own strength. When the current reaches the required point of strength, in some of the machines of this class, a portion is shunted off for use, while another portion is directed continuously through the coils of the inducing magnet, thereby maintaining its magnetism.

In other machines the whole of the current generated in the armature-coil is led through the magnet-coil before passing out to the external circuit.

Each of these three classes may be again subdivided into machines furnishing *alternating* and machines furnishing *direct* or *continuous* currents.

69. *Describe a machine of the first class mentioned.*

This class of machine is the simplest of any, and for a long time was the universal type of all magneto-machines in use. It is shown in Figure 27. A pair of coils, *c d*, of insulated wire, connected together in the

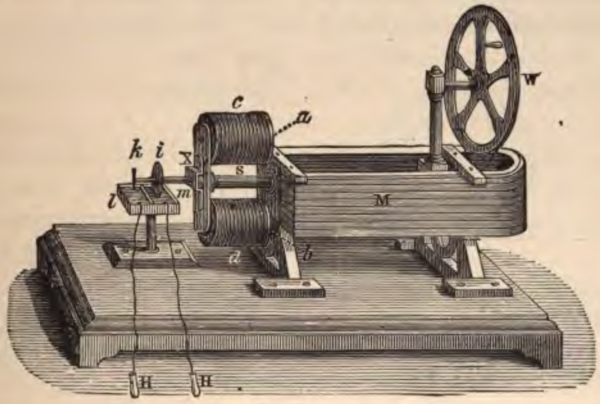


Fig. 27.

same way as electro-magnets, contain soft-iron cores, *a b*, united by a soft-iron yoke-piece, X; these are fixed on a horizontal axis, S, which may be revolved rapidly by means of a cord passing over a multiplying-wheel, W, and a pulley on the axis S, in front of the poles of a permanent magnet or series of magnets, M. The rapid alternate approach and retreat of the coils through the magnetic field of the permanent magnet induces currents in each coil, which, by means of a circuit-breaker, *k i*, dipping into a mercury bath having two chambers, *l m*, insulated from one another, are made intermittent, and thus shocks may be received from the handle-conductors, H H.

Dispensing with the circuit-breaker, the currents may be led off by suitable conductors. For some purposes, such as ringing bells, these reversed currents are used just as they come from the machine; but if the current is required to be continuous and to flow in the same direction constantly, as it necessarily must for many purposes, an arrangement called a *pole-changer* or *commutator* is attached to the axis of rotation and to the terminals of the coils, which brings both currents into the line in the same direction. The commutator, one form of which is represented in Figure 28, is an attachment on the armature-shaft, by which the two leading-out wires are reversed at the same instant that the currents are; so that, on the well-known principle that two negatives are equivalent to an affirmative, the current reversal does not become apparent.

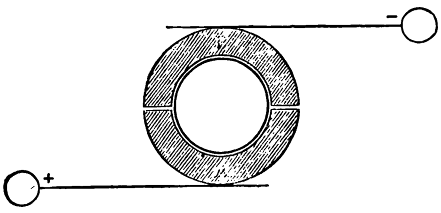


Fig. 28.

The above remarks do not refer to machines working upon the principle of the Gramme machine, since such machines originate a constant current in one direction.

Machines of the class just described may, and now often are, provided with a Siemens armature instead of the two helices fixed upon the soft-iron cores and yoke-piece.

70. *What was the first important advance made in magneto-machines after the invention of those already described?*

The invention of the Siemens armature. It was proposed in 1857 by Dr. Werner Siemens, and consists of a cylindrical piece of soft iron hollowed out at two sides for the reception of insulated wire wound longitudinally or parallel to its axis.

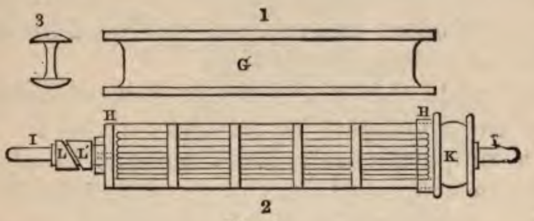


Fig. 29.

This armature is shown in Figure 29; No. 1 representing a side view, No. 2 the coiled armature, and 3 an end view thereof. In No. 1 G shows the hollowed sides before winding. In No. 2 L L is the commutator; H H brass bands which bind securely the bands of covered wire; I I are the axles on which the armature revolves, and K a pulley for a driving-belt. This armature is fixed on bearings in a magnetic cylinder formed by the extension of the poles of the permanent or electro magnet, which are joined together by brass or copper strips.

The Siemens armature is rapidly revolved within this chamber, and from its position directly between the poles of the magnet, where the magnetic field is much more intense than in that occupied by the old form of armature, much more powerful currents are produced. The terminals of the wire wound round the armature are led out of the chamber and convey the current to its desired destination.

71. *Describe a machine of the second class which illustrates the second great improvement.*

The machine which may be regarded as the type of the second class is that of Henry Wilde, of Manchester, England, who discovered that if the current produced by the revolving armature of a permanent magnet was made to flow through the coils of an electro-magnet, a degree of magnetism much stronger than that of the original magnet, was produced by revolving the armature sufficiently fast.

Having made this discovery, it then occurred to him that an electro-magnet so excited might be used to evolve a proportionately large amount of electricity. Making a machine embodying the principle, he discovered that such was the case. The following is a description of the Wilde machine, as patented by him in 1867:

A very large electro-magnet, A B, of the horseshoe pattern, forms the lower and much larger part of the machine, and is fixed with its poles downward; the yoke-piece joining the two electro-magnet cores is utilized as a base whereon to place a series of permanent magnets, M, also having their poles downward.

The permanent magnets are much smaller than the electro-magnet. Both magnets are provided with Siemens armatures, which are rapidly revolved simultaneously by the same power. The armatures rotate in what is called the magnet-cylinder.

This, in the upper cylinder, is formed by masses or pole-pieces of iron, *m n*, and in the lower by similar pole-pieces, T, attached to the poles of the magnet, and kept separate from each other by brass or copper plates, *o* and *i*; these are bored to make a cylindrical cavity.

The upper armature is rotated with a velocity of about twenty-four hundred revolutions per minute, and the current thereby obtained is directed, after passing through a commutator, to binding-screws, *p* and *q*, and thence through the coils of the electro-magnet below. These currents maintain the electro-magnet in a state of powerful magnetization, and the currents induced in its revolving armature are much more powerful than those of the exciting magneto-machine, and are utilized in the work done external to the machine. With such a machine an iron rod fifteen inches long and one-fourth of an inch thick was melted. Machines embodying this principle have largely gone into use during the last seven years for the generation of alternating currents, and are called "separately excited machines."

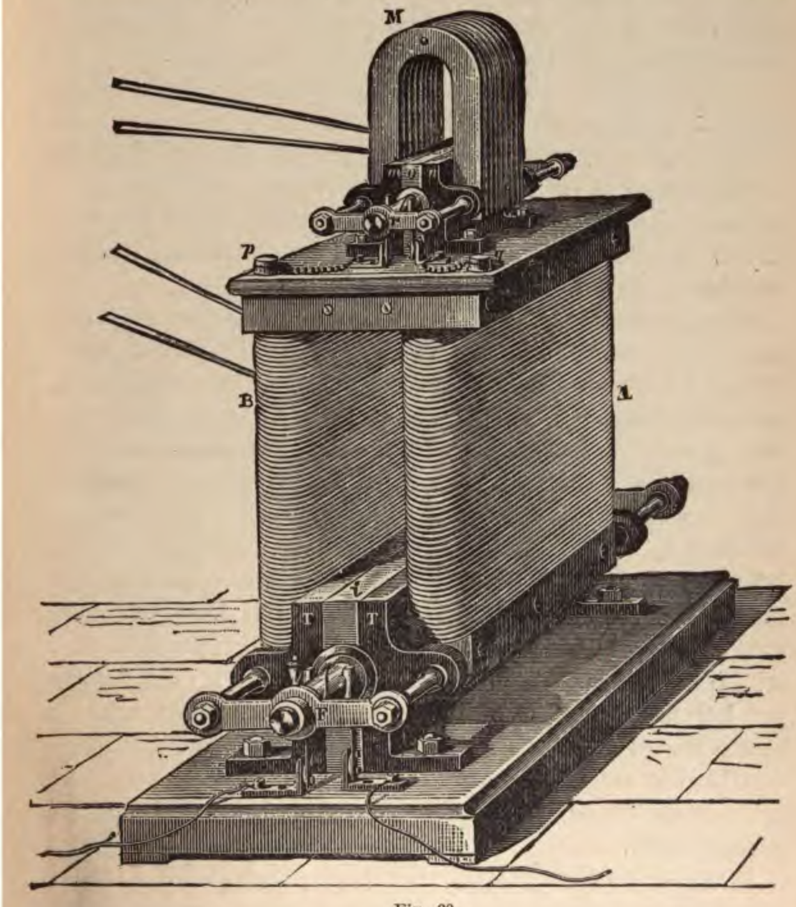


Fig. 30.

72. *Describe generally the machines of the third class which include the third great improvement.*

The principle on which the third class of machines is based was first patented in 1854, in England, by Soren Hjorth, of Copenhagen, who was indisputably its first discoverer, and also the first inventor of a machine whereby the said principle was made operative.

In December, 1866, the same principle was rediscovered and repatented by S. Alfred Varley, and in February, 1867, was communicated to the Royal Society by Professor Wheatstone and by Werner Siemens, each of these gentlemen having independently made the discovery, while neither of the latter appear to have known anything of the prior patent of Hjorth.

This principle is, briefly stated, "that electro-magnets, after being once magnetized, always retain a little magnetism; and that if the generating armature-coil of a magneto-electric machine be placed in circuit with the wire forming the helices of the inducing magnets, or if the latter are arranged to form a derived circuit with the circuit of the armature-helices, when the armature is rotated, infinitesimal currents are generated by means of the initial weak magnetism. These circulate round the helices of the inducing magnets and increase their magnetism, causing the production of stronger currents. These currents are again sent round the inducing magnet-helices, strengthening the magnetism still more; it again reacts on the armature, this mutual give and take continuing until the inducing magnets become saturated with magnetism, when the currents generated are of great power.

It must be understood that this principle of mutual accumulation is applicable to all machines provided with electro field-magnets. Nearly all the best and most powerful machines now constructed are arranged upon this principle; for example, those of Brush, Siemens and Alteneck, Gramme, Weston, Edison, Maxim, and others. One of the first machines made embodying the principle was that of Ladd; and a general description of Ladd's machine will suffice for all, as, although each machine has different details of construction and arrangement, the method of applying the accumulative feature is substantially identical in all.

Ladd's machine consists of two parallel electro-magnets, B B′. A Siemens armature, M, is placed at each end. They are, however, of different sizes. The smaller one is in circuit, by means of wires *p n*, with the coils of the electro-magnet, and the larger one furnishes the working current, which, by wires *p′ n′*, is led wherever desired. The two armatures are revolved simultaneously. The current is at first generated in the coils of the smaller armature by the residual magnetism of the electro-magnets. This armature, as it revolves, sends the currents generated in its coils through the coils of the magnet. The magnetism thus increased magnifies the currents induced in the revolving coils, and at the same time develops powerful currents in the larger

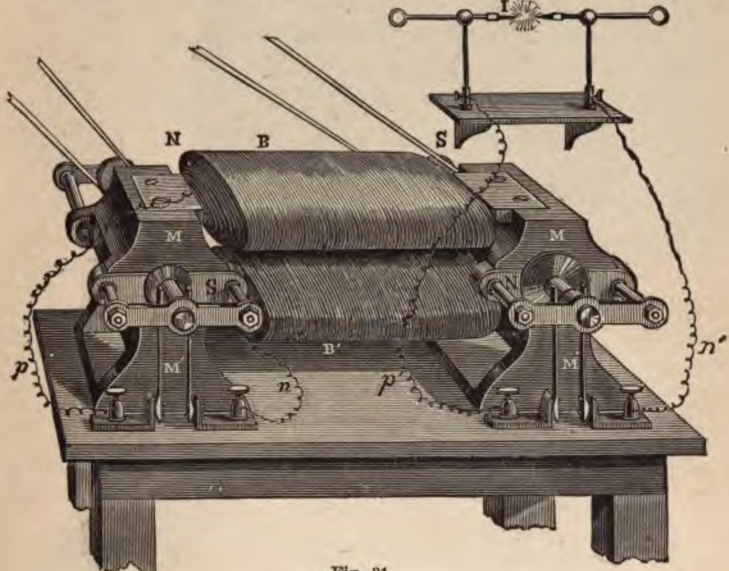


Fig. 31.

armature, thus carrying on the principle of mutual accumulation. The current developed in the larger armature is utilized for the purpose desired, which in the figure is represented as an electric light, I. Ladd's machine is really a combination of the ideas of Wilde with the principle of accumulative action.

73. *What is the principle and general construction of the Gramme and other ring-armature machines?*

The Gramme, Brush, and all machines using the ring-armature, have for their vital principle the simple fact of the substitution of the soft-iron ring for the rotating-shuttle armature of other machines. The ring armature was first proposed in 1860 by Dr. Pacinotti, of Italy; but

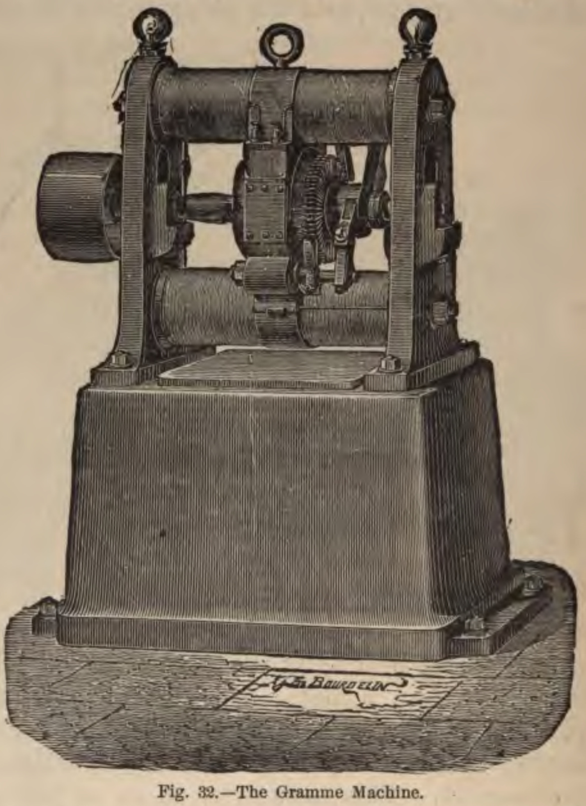


Fig. 32.—The Gramme Machine.

not until 1870, when re-invented and brought into use by Z. T. Gramme, was its utility recognized.

Its peculiar armature enables the Gramme and the numerous machines based thereon to evolve a continuous current in one direction without the necessity of employing a commutator, properly so-called. Instead of this the coil terminals are formed into a *collector*, as hereafter described.

The soft-iron ring is endless, and the insulated wire with which it is wrapped, and in which the electricity is induced, is also endless.

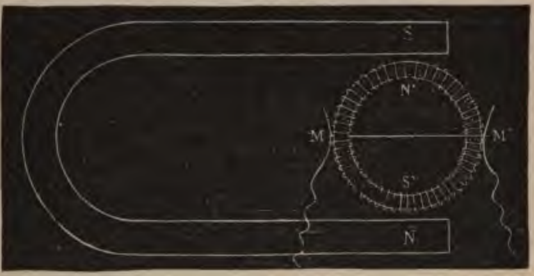


Fig. 33.

The wire is put on in separate coils, and the in-wire of one coil united to the out-wire of the next. But from each of these junctions between any two adjacent coils a branch wire is led to a metal plate on the axis of rotation of the ring. The metal plates which connect with these branch wires are symmetrically arranged round the axis, all insulated from one another, as shown in Figure 34, and metal brushes or springs press upon them at each side, nearly at right angles to the magnet poles; one of the brushes connecting with one of the leading-out wires, and the other with the second leading-out wire.

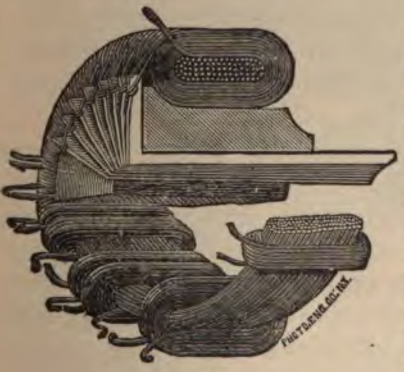


Fig. 34.

The operation of the ring is as follows: All the coils which at any given moment are in the semicircle on either side of one of the magnet poles—see Figure 33—say the north, are, when the ring is rotated, traversed by a current of one direction; and as these coils are all joined together in series, the current in one traverses all. Similarly, the semicircle formed by the coils immediately approaching, or immediately receding from, the south pole are at the same time traversed by a current of opposite direction. So long as the leading-out wires are open these currents have no outlet, and consequently oppose and neutralize one another. But if we close the external circuit the two currents, one on each side of the ring-coils, operate in the same way as a pair of batteries connected in multiple arc, both uniting in the same direction and issuing from the ring-coils together, giving to the brush on one side of the ring the effect of a plus pole, and to the other that of a minus pole, of a battery, the result being a continuous and non-alternating current.

It may be noted that the collection of metal plates ranged round the axis and forming the coil terminals is frequently but erroneously called the commutator.

74. *What are the chief peculiarities of the Brush machine?*

In it the ring-armature is made of cast-iron, and has its two flat surfaces divided into as many deep rectangular grooves as there are coils of insulated wire to be carried by the ring.

The ring itself is deeply grooved in its periphery, and the projecting sides which form the grooves are also grooved concentrically. These grooves serve to diminish the mass and weight, and also to ventilate the ring, to carry away a portion of the heat which generates during rotation, and to prevent and neutralize local currents of electricity which would otherwise operate against the efficiency of the machine. The armature-coils are wound in the rectangular grooves until the outermost convolution becomes flush with the sides of

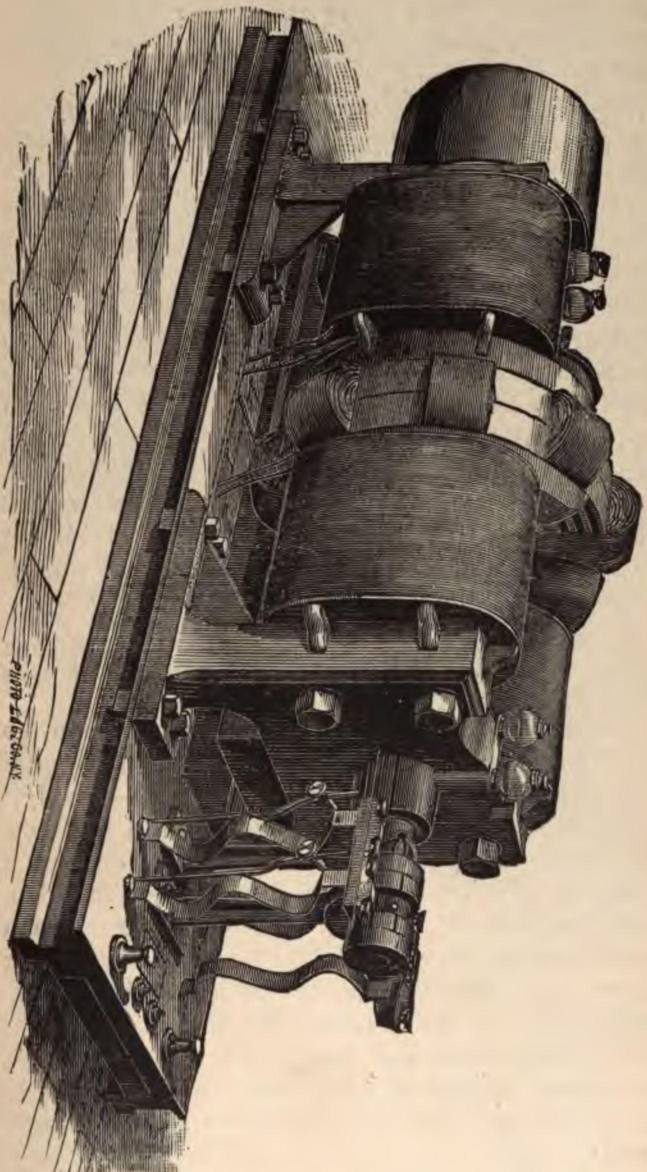

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Fig. 35.—The Brush Machine.

each groove. Thus when the ring rotates the side of each coil is caused to pass very close to the poles of the field-of-force magnets.

The coils work in pairs, the inner wire of one coil being united to the inner-wire end of the coil which is immediately opposite to it.

All the outer ends are led through the central shaft, which is hollow, and terminate in a commutator, which operates to cut out the two coils of a pair at the moment when they are passing the neutral point of the magnetic field and are not generating any current; this reduces the resistance of the machine when working. The circuit of any two of the coils thus cut out is also opened by the commutator, so that no current can circulate in them. The current is taken from this collecting commutator by suitable brushes, and the Brush machine, as well as those of the Siemens type, collect their currents by a system of coil terminals similar to that of the Gramme machine.

75. *What is meant by the term "dynamo-electric machine," and in what does such a machine differ from a "magneto-electric machine"?*

The term *dynamo-electric* has by common consent come to be exclusively applied to machines which are here placed in the third class described—namely, those in which the current is developed in the first place by the residual magnetism (which is never entirely absent from the iron core of an electro-magnet that has once been magnetized), and in which the current so developed is passed through the coils of the developing electro-magnet, thus increasing its magnetism, and, as a consequence of the increased magnetism, increasing also the current developed by it, the machine continually increasing its action, as it were, at compound interest up to a certain point, where the work of bringing the armature past the poles becomes so difficult as to balance the driving power.

The term dynamo-electric is also occasionally made to include machines of the second class, such as Wilde's, and, strictly speaking, is applicable to any form of machine (including even those which develop frictional electricity) by which work is transformed into electricity.

Many writers have explained the term dynamo-electric by stating that such a machine is one in which the field of force is produced by electro-magnets, in contradistinction to those in which permanent magnets are used; the latter being termed magneto-electric machines.

It is obvious that this explanation is incorrect, except in so far as it conveys the idea that machines employing permanent field magnets cannot be utilized on the mutual-accumulation plan.

The following views, it is believed, will, if examined carefully, be found to be correct:

First. All machines in which the electricity is developed by moving a closed wire circuit through a magnetic field of force, whether that field be produced by permanent or electro-magnets, or whether the magnetism be produced by self-developed electricity or by electricity furnished by an external exciter, are true *magneto-electric* machines.

Second. All machines by which energy in the form of moving power is transformed into energy in the form of electricity are properly called *dynamo-electric* machines.

Inasmuch as these terms are almost universally applied erroneously, it may be well to add other definitions as follows, so that the student may be fully informed not only as to the correct meaning of the terms, but also as to the incorrect but popular understanding:

Dynamo-electric machines, according to the popular acceptation of the term, are those in which the reaction principle of mutual accumulation is employed; or those which have separately excited electro-field magnets.

Magneto-electric machines are usually and popularly understood to be those in which the field of magnetic force is produced by permanent magnets only.

Machines which excite their own field-magnets are of two general types—*i.e.*, those in which the field-magnets, armature, and external circuit are all united in one serial circuit, as shown in diagram in Figure 36; and those in which only a part of the current generated by the armature is passed through and excites the field-magnets, as diagrammatically represented in Figure 37. This form is coming into more extended use, having been first proposed by Wheatstone, and is known as the *shunt dynamo*.

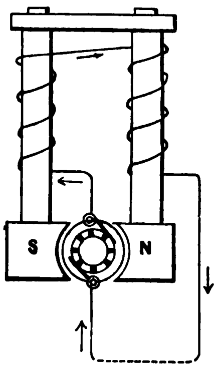

Fig 36.

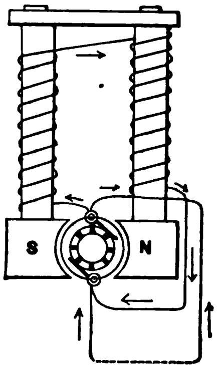

Fig. 37.

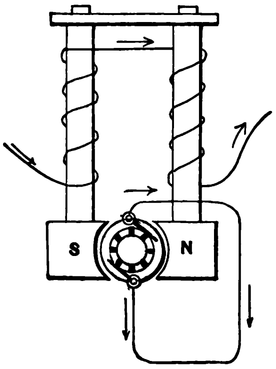

Fig. 38.

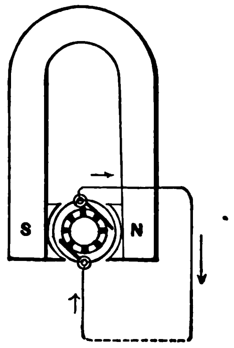

Fig. 39.

Machines of the character proposed by Wilde—viz., ose in which the field magnets are energized by currents derived from an external source—are called *separately-excited dynamos;* and the principle of arrangement is shown by Figure 38. Finally, to make clear the arbitrary distinction between so-called magneto-electric and dynamo-electric machines, and to show that it is more a matter of nomenclature than anything else, the former, or a machine in which the field-magnets are of the permanent character, is represented by Figure 39.

76. *For what purposes are constantly alternating currents used when produced by magneto or dynamo-electric machines?*

For printing or dial telegraphy, for signal bells in telephony, and for some systems of electric lighting, chiefly the Jablochkoff candle system, several of the British and French lighthouse lamps; and as the primary current in transformer systems of electric lighting and welding.

77. *For what purposes are magneto or dynamo-electric currents of continuous direction chiefly employed?*

Principally for electric lighting, either by arc or incandescence; for electro-plating and electrotyping; for the transmission of power, and for furnishing currents for long telegraph lines.

CHAPTER VII.

INDUCTION-COILS AND CONDENSERS.

78. *What is an induction-coil, and why is it so called?*

It is an instrument whereby a weak current of high electro-motive force may be transformed into a stronger current working under a lower electro-motive force, or the reverse. Induction-coils, according to their direction of transformation, have been popularly termed step-up or step-down coils. Since 1883, the latter have been much used in electric lighting for the purpose of transforming alternating currents working with a high electro-motive force but having comparatively little strength (these flowing in a long main circuit, including the primary helices of the appliances), into strong currents circulating in a short circuit under a low electro-motive force, and have been called transformers, secondary generators, or converters.

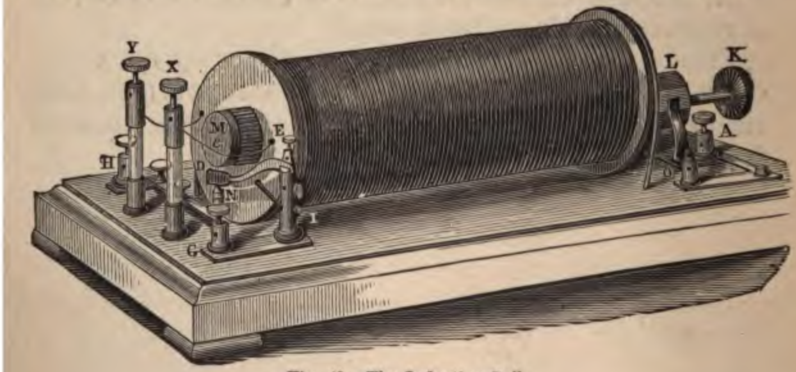

Fig. 40.—The Induction-Coil.

If the two coils of the inductorium are of different lengths, and the longer one be used as the primary helix, the E. M. F. will be lowered in conversion; if, however, the shorter one be used as the primary, the E. M. F. will be raised.

An induction-coil of the class last mentioned is shown in Fig. 40. It consists of a short coil of comparatively thick insulated wire, around which is wound a very long coil of fine wire. In the centre of the coarse wire coil is placed a core of soft iron or a bundle of soft-iron wire. The thick wire coil is placed in circuit with a battery and circuit-breaker.

In the figure K is a screw for turning the reversing commutator, L; E is the body of the coil; M the soft-iron core, provided with a solid cap, *e*; D is the hammer of the circuit-breaker, N; and Y and X are the terminals of the secondary coil.

The induction-coil was invented by Professor Charles G. Page, of Salem, in 1836; brought to a state of great perfection in the shop of Ruhmkorff in 1851, and in 1857 much improved by Ritchie, of Boston. It is both a magneto-electric and an electro-magnetic apparatus, because the induced current which manifests itself at the terminals of the fine wire coil is formed by the conjunction of a magneto-electric current, caused by the rapid magnetization and demagnetization of the core as the voltaic current in the coarse wire coil is alternately made and interrupted, and of that excited in the fine wire coil by electro-dynamic induction from the coarse wire coil during the same contacts and interruptions.

To particularize: We have already seen (18) that when a closed circuit is in proximity to a conductor which is in connection with a voltaic battery, at the moment a current arises or ceases in that conductor another current of momentary duration arises also in the closed circuit near it. We have also seen that when a magnet is moved near a coil of wire, or a coil of wire near a magnet, a current is developed in the coil on the approach of the two, and another in an opposite direction as they are parted.

These effects are combined in the induction-coil, as the coarse wire coil performs two duties at the same time—

namely: 1st. That of advancing and withdrawing the inducing magnet, which it does most effectually by alternately causing the soft-iron core in its interior to become magnetized and demagnetized. 2d. That of causing, by the make and break of its own circuit, momentary currents of electricity of rapidly alternating direction.

Thus we see that the voltaic induced currents are superadded to those induced by the core in its magnetization and demagnetization, to form the induced currents circulating in the fine wire coil.

The instrument is called the induction-coil because the currents of the secondary coil are produced solely from inductive causes; and the electro-motive force thus induced in a long coil is so enormously greater than that of its inducing battery as to assume an appearance very similar to that of frictional or mechanical electricity.

79. *What is the primary circuit, and what is meant when we speak of a primary current?*

The *primary* circuit or coil is the coil of comparatively thick wire which is connected with a battery and circuit-breaker. Within it is inserted the soft-iron core, and it is itself inserted within the coil of fine wire. It may also be called the main or inducing circuit, but the term primary circuit literally means "the first circuit." It is called the primary coil because it is employed for the conveyance of the battery current. It will hereafter be understood that whenever the word primary is used with reference to induction-coils it is intended to signify the battery circuit. When we speak of the primary current we mean the battery current that traverses the primary coil. It is sometimes called the inducing current.

80. *What is meant by the terms secondary coil and secondary current?*

The *secondary coil* is the long coil of fine wire which surrounds the primary coil, and in which the momentary currents, induced by the primary coil and core, are developed.

The wire of the secondary coil is much longer and thin-ner than that of the primary. It is called the secondary coil, both in contradistinction to the primary coil and because the currents set up in it are dependent entirely for their existence on the first or primary current, which circulates in the primary coil and excites magnetism in the core.

As the induced currents are much more powerful than the primary currents, it is necessary to be much more careful in insulating the wire composing the coil.

The *secondary* or *induced current* is the current or, more properly, the series of currents which are excited in the secondary coil by the rapid magnetization and demagnetization of the soft-iron core in conjunction with, and caused by, the make and break of the primary circuit. This current has a much higher electro-motive force than the battery or primary current.

81. *What is the circuit-breaker, and why is it necessary?*

In an induction-coil the circuit-breaker is the arrangement applied to the primary wire, which, forming part of the actual circuit, alternately completes and interrupts it. It is generally, in ordinary coils, automatic, or self-acting; for the soft-iron core is often made use of to work the circuit-breaker.

An iron plate or armature is fixed to a flat spring, opposite one of the ends of the core, and, when not in operation, it presses against a metallic contact-stop by the elasticity of the spring. The circuit of the battery and primary coil passes through this armature-spring and contact-stop. For example: Starting from the positive pole of the battery, the path of the current is first to the metallic contact or back stop; thence to the armature and spring; then to one of the primary coil terminals, through the coil, and from the other terminal to the negative pole of the battery.

Now, when the battery is connected, to put the coil in operation the current passes through the primary coil and causes the core to become magnetic. The armature is then attracted to the core and away from its back contact. This breaks the circuit; the magnetism disappears; the armature, under the influence of the spring, falls back, closing the circuit; this action of alternately establishing and breaking the continuity of the primary circuit is repeated indefinitely.

The rapidity of the vibrations is regulated by an adjusting screw. The circuit-breaker is sometimes worked by a separate electro-magnet and sometimes by clockwork or other mechanical movements. In one form or another it is an indispensable adjunct to the induction-coil, because, as we have seen, the number of induced currents depend entirely upon the breaking and closing of the primary circuit, and the consequent change of magnetism in the core.

If we close the primary circuit once, we merely get one pulsation of current in the secondary coil. If we then open the primary we again perceive but one pulsation in the secondary coil, but this time in the opposite direction. Hence, if we rapidly break and close the primary circuit we see there is a corresponding succession of alternating currents in the secondary coil.

82. *What is meant by the extra current?*

It is the name given to a current set up in the primary coil by induction between the several convolutions of the same wire when a current is sent through it. It is produced both on making and interrupting the battery contact, but is much stronger when the circuit is broken, because then the extra current is in the same direction as the primary currents; but when the circuit is made the extra current is in opposition to the primary current, which, as it were, arouses an opponent in its own path. Thus we see that the action of the primary coil, in addition to inducing a current in the secondary coil, also induces a current itself. This current is made apparent in the following manner: If we attach the two coils of a
e to a battery, and place a contact-breaker in circuit,
fine spark will be observed on breaking contact.

we wind the piece of wire into a helix or spiral we will at once notice that the spark is much larger and brighter. This is caused by the action of the extra current, which, as previously stated, is on breaking contact, in the same direction as the battery current, and the spark is the combined effect of the two currents.

The extra current caused when contact is made is called the *inverse current;* when caused by breaking contact it is called the *direct current.* The phenomena caused by the extra current were first noticed by Professor Joseph Henry in 1832. It was subjected to experiment by Faraday in 1834, who proved that both the spark and shock given on breaking contact were due to this cause.

In order to overcome the injurious effects of the extra current the circuit-breaker is frequently bridged or looped by a *condenser.* By thus bridging the circuit-breaker the iron is demagnetized with greater rapidity, and the spark is also considerably lessened.

The extra current of breaking contact enters the condenser, and accumulates on its plates instead of jumping across the points of the circuit-breaker in the form of a spark ; one of the condenser-plates being charged plus and the other minus. As the current flows from one terminal of the helix to the other, one end will draw plus electricity from, and the other add plus electricity to, the condenser-plates. When the circuit is again closed the charge in the condenser aids the battery current, because its discharge coincides with the direction of the battery current, and therefore the opposing force of the extra current is lessened by the combined forces acting against it.

83. *What is a condenser?*

It is an arrangement of conducting surfaces by which a great quantity of electricity can be accumulated upon a comparatively small area.

It is based upon the law that "the capacity of a conductor is greatly increased when it is placed near to another conductor charged with the opposite kind of electricity." Any apparatus which consists of two good conductors, which are separated from each other at a small distance by a non-conductor, may properly be called a condenser.

A Leyden jar, therefore, which usually consists of two tinfoil surfaces separated by a dielectric of glass, constitutes a condenser.

As usually constructed for use in telegraphy or in connection with induction-coils, the condenser consists of alternate layers of tinfoil and paper saturated with paraffine. Each alternate metal plate is connected so as to form two distinct series, insulated from each other by the interleaved sheets of paraffined paper. The two series of plates are each united to binding-screws which form the terminals of the plates and may be conducted in any desired way; as, in the induction-coil, one terminal is connected with one side of the circuit-breaker, and the other terminal with the other side of the same. It is usual to represent a condenser by the conventional sign of a series of thin lines interleaved with one another, as in Figure 41.

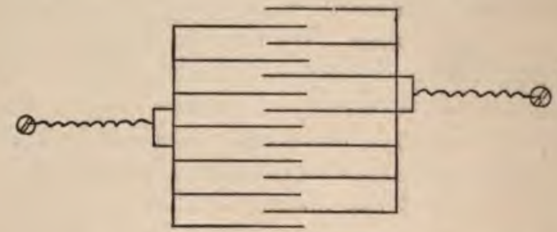

Fig. 41.

84. *Why is a soft-iron core inserted within the primary coil?*

Because, in the first place, without it the current produced in the secondary coil would be caused solely by dynamic induction from the battery current circulating in the primary coil, and in that case would be comparatively weak; while when the core is inserted it is alternately magnetized and demagnetized by the rapid make [illegible] break of the battery circuit, and so induces a mag[illegible]electric secondary current, which adds its effect to that of the current caused by the voltaic or dynamic induction, and makes the combined effect very strong and intense. In the second place, the soft-iron core is often utilized as an electro-magnet, and in that capacity is made to attract the contact-breaker, thus effecting by its own magnetism the rapid interruptions of the battery current.

As it is important for the proper operation of an induction-coil that the core shall gain and lose its magnetism very quickly, it is usually composed of a great number of unpolished soft-iron wires, which are partly insulated one from another by a thin coating of oxide. The circulation of induced currents in the substance of the iron is thus prevented.

85. *Give a brief description of some of the largest induction-coils which have been made.*

The coil made by Ritchie, of Boston, for Mr. Gassiot, is one of the most powerful instruments constructed. The primary coil is of No. 9 wire, Birmingham gauge, and is wound in three layers, the length being 150 feet. This coil has a gutta-percha case, over which is placed a glass tube. Over this again is arranged the secondary coil, divided into three sections, each five inches long, and wound on glass cylinders. The total length of the secondary wire is 73,650 feet, or nearly fourteen miles, and the core consists of a bundle of soft-iron wires, the bundle being eighteen inches long and about an inch and three-quarters in diameter. The contact-breaker is worked by a ratchet-wheel turned by hand. This coil, with five cells of Grove battery, has given sparks twelve inches and a quarter long.

Ritchie has since constructed a coil for the Stevens Institute of Technology which has a primary coil made of No. 6 wire and 195 feet long. The core is a bundle of No. 20 iron wires, and the secondary wire is more than 50 miles long and is made of No. 36 wire. It has, using 3 large bichromate cells, given sparks 21 inches in length.

The largest coil made is that of the Polytechnic Institute, London. Its primary coil weighs 145 pounds and is 11,310 feet long, while the secondary wire is 150 miles long, weighs 606 pounds, and has a resistance of 33,560 ohms. The core is a bundle of No. 16 iron wires, and as a whole is 5 feet long and 4 inches in diameter. The entire instrument is 9 feet 10 inches long and 2 feet in diameter. This coil has given sparks 29 inches in length.

Perhaps, however, the most wonderful machine of this class is that constructed by Mr. Apps, of London, for Mr. Spottiswoode, of the Royal Society. It is capable of producing sparks 42 inches in length. It has two primary coils, which can be readily substituted for each other. One is intended for the production of long sparks, the other for short and thick sparks. The secondary coil consists of 280 miles of wire. Its resistance is 110,200 ohms; and the total number of convolutions is 341,850. The first primary coil is 990 feet long, has a resistance of $2\frac{8}{10}$ ohms, consists of 1,344 turns in 6 layers, and weighs 55 pounds. It has a core consisting of a bundle of iron wires, forming together a core 44 inches long, upward of $3\frac{1}{2}$ inches thick, and weighing 67 pounds.

86. *What are the uses of the induction-coil?*

It is a valuable agent in chemical and physical research; has been used in mines to furnish electric light in hermetically-sealed tubes, and also, in the place of the frictional machine, to charge Leyden jars. It is extensively employed for medical purposes, and has by Siemens and Halske been applied to telegraphy. As already indicated, it has of late extensively been applied in the inductive distribution of electrical energy for lighting purposes; it is the principal agent in furnishing currents of great volume for welding and like electric metal-working processes. For gas-lighting it has been very useful, and, last but not least, has been successfully dapted to battery telephones.

CHAPTER VIII.

DEFINITIONS OF ELECTRICAL PROPERTIES, TERMS, AND UNITS.

87. *What is the meaning of the term potential when used in electrical science?*

Potential is a word which literally means *power to do work*, and is used to denote the electrical condition of any body, or the degree to which that body is electrified.

As we shall hereafter see, a large quantity of electricity imparted to a conductor of small capacity will electrify it up to a very high potential. The higher the potential of any electrified body the greater is its tendency to pass to a point of lower potential, and consequently the greater its power to do work or overcome resistance in so passing. We find that it is customary to refer to positively electrified bodies as being electrified to a high potential, and to bodies which are negatively electrified as having a low potential.

Precisely as we take the level of the sea as a zero-point in measuring the altitude of mountains or the depth of mines, so we take the electrical condition of the surface of the earth and assume it to be the potential zero-point, all bodies positively electrified having a higher potential than the earth, and all bodies negatively electrified being assumed to have a lower potential than the earth; thus the potential of any other body is the difference between the electrical condition of the other body and the earth. No body can be said to have an absolute potential, but for brevity the word is used by itself to signify the difference; precisely as, speaking of a Fahrenheit thermometer, we would say, "The degree of heat is 60 degrees," meaning thereby 60 degrees above zero. The meaning is practically the same as the word *tension*, generally used in the older text-books of electricity.

Whenever electricity moves, or tends to move, from one place to another, there is said to be a *difference of potential* between those two places.

The place *from* which the positive electricity tends to move is assumed to be of higher potential than the other. The difference of potential between any two points expresses the amount of work which each unit of the electricity could do on its journey if it could all be utilized to do work instead of having to overcome the resistance of a circuit.

In a voltaic battery the difference of potential between the two ends of the battery is always maintained by chemical energy or work, and therefore the flow of current keeps up indefinitely; for so long as the plates of the battery are at opposite potentials, so long the current must continue.

88. *What is meant by electro-motive force?*

The term electro-motive force means that property of any source of electricity by which it tends to do work by transferring electricity from one point to another.

For the sake of brevity it is frequently written E. M. F. It is produced by difference of potential, and in practice may often be considered to be the same property. "Just as in water-pipes a difference of level produces a pressure, and the pressure produces a flow so soon as the cock is turned on, so difference of potential produces electro-motive force, and electro-motive force sets up a current so soon as a circuit is completed for the electricity to flow through." *

The electro-motive force of a battery is the power which it has of overcoming resistance. It increases in direct proportion to the number of cells employed—ten cells having exactly ten times the electro-motive force of one cell—but is not in any way dependent on their size, since a cell as small as the bowl of a tobacco-pipe possesses as great an electro-motive force as a cell of the same materials which would hold a gallon. The electro-motive force of the Daniell battery in volts is 1.079; and that of most of the copper-sulphate forms, about the same. The Grove is 1.956, chromic acid 2.028, Leclanché 1.481, and the Smee, when in action, 0.482.

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* "Electricity and Magnetism," S. P. Thompson.

89. *What is the meaning of the term resistance?*

It has been already stated that some substances possess the property of allowing electricity to diffuse itself freely and readily through them, and are therefore called *conductors*, while others offer much opposition or resistance to this diffusion, and are hence called *non-conductors* or *insulators*. These terms are not absolute, as even the best conductors offer some obstruction to the passage of the current, and the best insulators will in some measure conduct electricity. Resistance, then, is the name given to this obstruction which is offered to the passage of the current by the substance of the circuit through which it passes; and when it is very great it becomes *insulation*. It is a property of every substance, and in each substance differs in degree, from silver, which offers the least resistance to the current, to gutta-percha or india-rubber, which offer a very great resistance indeed.

In a telegraph line the total resistance is composed of the resistances of the line wire, the earth, the instruments, and the internal resistance of the battery.

The resistance of any given wire increases in exactly the same proportion as the length of wire is increased; for instance, fifty miles of No. 12 wire offer exactly fifty times the resistance of one mile. It also decreases in proportion as the area of the cross-section is increased; for example, a wire one mile in length, with a cross-section having an area of a square inch, offers just one-fourth the resistance of a wire the same length whose sectional area is one square half-inch—because the square half-inch is contained just four times in the square inch.

To make the idea as plain as possible, the resistance of a wire increases with increased length, keeping the gauge the same, and decreases with increased weight, keeping the length the same. Resistance may be defined as that quality of a conductor by which the strength of current developed from a given E. M. F. is determined.

90. *What is the meaning of the word quantity, when applied to electricity?*

When applied to static electricity no clearer definition can be given of the term quantity than the term itself; and there is no reason why it should not have the same meaning when applied to electricity that it has when applied to any other force or substance, visible or invisible.

The fact that we do *not* know that electricity has a separate existence, or is a distinct entity; or that we *do* know that it is not an element, a fluid, or a substance, need not prevent us from speaking of its quantity, since we commonly speak of quantities of sound, light, and heat, without at all implying that a mass or volume of anything is actually present. When any body is charged with electricity it is very evident that the electricity is there; that a certain well-defined amount is present, and that such an amount can be measured by an electrometer. When we, therefore, speak of such a quantity of electricity we simply mean the amount of electricity present.

The word quantity, applied to current electricity, means literally the strength of the current, or the amount per second acting to produce heat, magnetism, chemical action, or any other of its effects.

The strength of current must not be confounded with the strength of the battery which produces the current, but it may be termed the amount of electricity realized. It is the margin of effective electricity produced by any battery after the resistance of the circuit has been overcome.

All the most remarkable effects of the current, such as electrolysis, combustion of metals, the deflection of the galvanometer, and the production of magnetism and heat, are dependent on the quantity of electricity passing.

The quantity of electricity passing in a given circuit can be increased by increasing the electro-motive force, without proportionately increasing the resistance; or by diminishing the resistance.

91. *What are the standard units used in electrical measurements?*

A unit is the base of any system of measurement. Electricity has properties which it is frequently necessary to measure in order that its working value may be properly estimated.

Now, that we may be able to state the results of such measurements, it is essential that we must have some standard terms which, when expressed, convey to the mind definite ideas, precisely as in measuring a distance we would say so many feet; or in expressing the capacity of a tank, so many gallons; or the contents of a solid block, so many cubic feet.

Further, when one substance has several properties a different system of measurement is required for each property; for as in a cubic block of wood we should measure one side of its surface by superficial measure, its contents by cubic measure, and its weight by still another system, and would state the result differently in each case, so the different electrical measurements each have their own units, in which the results are expressed.

Designations have been given to the electrical units from the names of distinguished electricians and scientists. Thus the unit of electro-motive force is called the *volt*, from Volta; the unit of capacity is called the *farad*, from Faraday; the unit of resistance is called the *ohm*, from Ohm, the German physicist; while the units of current and quantity are named respectively the *ampère* and the *coulomb*.

92. *What is the meaning of the term volt?*

The volt is the name of the practical unit of *electro-motive force* and of *difference of potentials*. Its precise value is 0.9268 of a Daniell cell in good condition; in other words, the Daniell cell is equal in E. M. F. to 1.079—one volt and seventy-nine thousandths. The Daniell cell may, therefore, for practical purposes be said to have an electro-motive force of one volt.

The volt is equivalent to the electro-motive force required to produce a current of the strength of one ampère in a circuit having a total resistance of one ohm.

An E. M. F. equal to one million volts is called a megavolt, and one-millionth of a volt is called a microvolt.

93. *What is the standard unit of resistance, and how may it be defined?*

The unit which is almost universally used in this country and in England is that fixed upon as a standard by a committee of the British Association. It is therefore sometimes called the B. A. unit, but more frequently the *ohm*, from Ohm, the distinguished German mathematician, who first ascertained the laws of electrical resistance. It is a unit of *resistance*, in the same way that an inch is a unit of length or an ounce that of weight, and is approximately equal in resistance to a wire of pure copper one-twentieth of an inch in diameter and two hundred and fifty feet long, or of one-sixteenth of a mile of No. 9 galvanized-iron wire of the ordinary quality. The resistance of the ohm is that of a column of pure mercury 106 centimetres (41.73 inches) long, 1 square millimetre (.00155 square inches) in sectional area, at a temperature of zero centigrade.

This definition is that of the unit termed the legal ohm, which, however, is not often used in practice either the United States or in Europe.

The ohm which is generally used is equal to 0.9889 legal ohm. A microhm is a millionth of an ohm, and a megohm is equal to a million ohms.

94. *What is the unit of current strength, and how may it be defined?*

The name of the unit of current is the *ampère*, which was adopted at the Electrical Congress of Paris in 1882.

It represents the *strength of current* passing in a circuit having a total resistance of one ohm, with an E. M. F. of one volt. If the E. M. F. and the resistance both remain constant, the current strength will also be constant.

Thus, if, speaking of a given circuit, we say that it has a current of fifty ampères, and we know that the resistance of the circuit is fifty ohms, we see at once that the E. M. F. must be twenty-five hundred volts. To calculate the strength of current we use Ohm's law and divide the electro-motive force by the resistance. A milli-ampère is a thousandth part of an ampère, and is useful in computing magnitudes where the current strength is not great. The currents employed in telegraphy vary from four to two hundred and fifty milli-ampères, the latter being the approximate current strength flowing in an ordinary local sounder circuit; currents utilized in electric lighting vary between one and fifty ampères.

95. *What is the unit of quantity?*

This unit is termed the *coulomb.* The coulomb denotes the *amount of electricity* which a current of the strength of one ampère can furnish per second of time.

In other words, it is the amount of electricity furnished in one second by an electro-motive force of one volt in a circuit having a total resistance of one ohm.

It may also be defined as the amount of electricity which, with a difference of potential of one volt, will fully charge a condenser having a capacity of one farad.

96. *What is the unit of capacity, and how may it be defined?*

The *farad* is the unit of *capacity*, and is as necessary as a unit of resistance or electro-motive force. It is used in determining the amount of charge a condenser is capable of. A condenser or Leyden jar of the capacity of one farad is one which is fully charged by the amount of electricity which, with an electro-motive force of one volt, would flow through a resistance of one ohm in one second of time.

It may also be defined by saying that it represents the capacity of a condenser which contains one coulomb of electricity when the difference of potential between its opposing plates is one volt. A microfarad is a millionth of a farad, and a megafarad is one million farads.

In actual practice the farad is much too large a quantity, and the unit adopted is the microfarad.

97. *What is Ohm's law?*

It is one of the most important of the laws which govern the transmission and distribution of electricity, and was promulgated by Dr. G. S. Ohm, of Nuremberg, Germany, as early as 1827. Stated as concisely and plainly as possible, it is as follows:

The effective strength of current in any given circuit is equal to the electro-motive force divided by the total resistance; and it is the basis of all electrical measurements.

It may also be represented as below: In any circuit the strength of current is equal to the E. M. F. divided by the resistance; therefore the resistance equals the electro-motive force divided by the current, and the electro-motive force equals the current multiplied by the resistance.

It is obvious, then, from the above considerations that, knowing two of these magnitudes, we can readily calculate the third.

To obtain definite results we must use definite units; for example, we will suppose a battery of 100 cells, and call each cell an E. M. F. of one volt, which will give us a total E. M. F. of 100 volts. We will further suppose a resistance in the battery itself of 20 ohms, and in the line and instrument of 30 ohms, making a total resistance of 50 ohms. Now, as the E. M. F. divided by the resistance gives the current, all we have to do is to divide the 100 by 50, and we have a quotient of 2—showing that with an E. M. F. of 100 volts, and a resistance of 50 ohms, the strength of current flowing in the circuit is equal to two webers, or ampères.

It follows, then, that if the electro-motive force is increased, while the resistance is maintained the same, the strength of current is also proportionately increased; and that if the resistance of the circuit is increased, while the E. M. F. is left unaltered, the current is proportionately decreased.

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CHAPTER IX.

ELECTRICAL MEASUREMENTS.

98. *What is a galvanometer?*

A galvanometer is an instrument for detecting, indicating, or measuring currents of electricity.

When used only for detecting or indicating such currents the instrument is more properly called a galvanoscope. Galvanometers are made in many forms and are used in several different ways, but are all based on the fundamental fact that a magnetic needle is deflected from its natural position by the passage of a current of electricity in a conductor placed parallel to it. When the conductor is carried over the needle and back on the other side, as in Figure 42, the effect is doubled; and, of course, if we repeat the operation a great many times, using insulated wire, thus forming a coil in which the needle is freely suspended, the effect may be multiplied almost indefinitely.

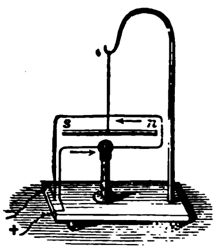

Fig. 42.

All galvanometers, then, consist of a coil of insulated wire and a magnetic needle delicately suspended, so as to be easily deflected by the passage of a current through the coil. These, in conjunction with a dial-plate, graduated so that we may intelligently interpret the movements of the needle, are the only essential features of the instrument.

Horizontal galvanometers are more sensitive than vertical ones and are in more general use, a very good form for use in connection with a Wheatstone bridge being shown in Figure 43. In using a galvanometer for any purpose an instrument of low resistance is the fittest one to use for testing low resistances; and the greater the resistance to be tested the finer should be the wire, the greater the number of convolutions, and, consequently, the higher the resistance of the galvanometer.

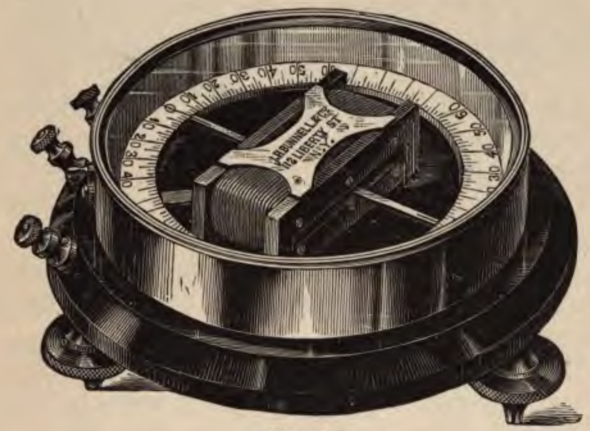
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Fig. 43.

99. *When and by whom was the galvanometer invented?*

The galvanometer is one of the earliest results of Oersted's discovery. It was, in fact, in the same year (1820) that the first galvanometer was invented by Professor Johann S. C. Schweigger, of Halle, who passed a number of turns of insulated wire round the compass needle, thus multiplying the galvanic effect and constructing a galvanometer. An instrument of different form was soon afterward independently devised by Johann C. Poggendorff, of Berlin; and, as a description of this latter was published prior to that of Schweigger, Poggendorff has been thought by some to be the original inventor.

The invention of the galvanometer is the basis of the needle system of telegraphy.

100. *What are the principal galvanometers now in use?*

The tangent and sine galvanometers, the differential, Thomson's reflecting galvanometer, and those con-

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structed on the Wheatstone bridge principle, which latter usually comprise also the necessary resistance-coils.

101. *What are the principal uses of a galvanometer?*

Besides the use implied by the name—*i.e.*, that of detecting and measuring galvanic currents—the galvanometer is invaluable in practical telegraphy, and is employed in the testing and measurement of instruments and circuits for conductivity resistance; and the latter also for insulation resistance. It is also used in the localization of faults on telegraph lines and in cables; in the measurement of internal resistance, and estimation of the electro-motive force of batteries; and, in the case of long submarine lines, as a receiving instrument for telegraphic signals.

102. *What is an astatic galvanometer?*

It is a peculiar arrangement suggested by Professor Cummings in order to increase the sensibility of the galvanometer. Two needles are freely suspended on the same axis, parallel to each other, but with their poles placed in contrary directions—the north pole of the upper being directly over the south pole of the lower. The sensibilityof the galvanometer is increased, because the directive force of the earth is neutralized, since the two needles are opposed to each other. If the needles could be made exactly equal to each other in magnetic power they would stand indifferently in any position in which they were placed; but in practice one needle is always a little stronger than the other, and the pair will, therefore, settle in a north and south direction. Each needle may have its own coil, the coils being joined so that the current circulates in opposite directions around the two and deflects both needles similarly. On the same axis with the needles, but above the graduated circle, is a pointer to denote the deflections. The nearer the two needles are to each other in magnetic

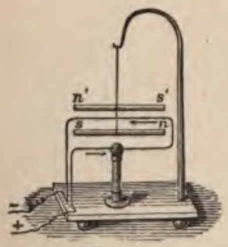

Fig. 44.

strength, the slower will be the vibrations of the pair and the greater the delicacy of the galvanometer.

Two needles so mounted and arranged in coils constitute an astatic galvanometer.

103. *What is a tangent galvanometer, and how is it used?*

It is an instrument invented by M. Pouillet, a French electrician. Its principle is that *the strength of current, as measured by the tangent galvanometer, is proportional to the tangent of the angle of deflection of the needle.* It is thought by many electricians to be the most useful and convenient form of galvanometer for general purposes. It consists essentially of coils of wire wound in a deep groove in the circumference of a brass ring about six inches in diameter, with a small magnetized needle hung at its centre and moving over a graduated circle. The length of the needle must be small compared with the diameter of the coil, in order that the influence of the coil may, as far as possible, be the same whatever the angle of deflection of the needle.

A form of this instrument is made in the United States with the above object specially in view. It was devised by Dr. Bradley, of Jersey City, and is described as follows: "The needle is composed of several parallel strips of steel, mounted on a ring of aluminum, and trimmed to form a circle. By this means all parts of the needle are subjected to the influence of the coil throughout the entire deflection. Four coils are used, the first about 150 ohms resistance, the second 25 to 30 ohms, the third one or two ohms, and the fourth is a strip of sheet copper or brass, which is wound two or three times around the needle."

The first coil is used for high resistances, the last for very low resistances, and the other two for medium resistances.

It will do no harm to state here, for the benefit of the student who is no mathematician, that a *tangent* is a straight line which touches at any one point the circumference of a given circle.

In the case of the tangent galvanometer the dial of the instrument is the given circle, and the point at which the tangent touches the circle must be the zero-point.

The tangent is, therefore, an imaginary line, which must be parallel to the diameter that connects the degree of ninety on one side to the same degree on the other side, and at right angles to the diameter, or line connecting the two zero-points. Now, if the needle is deflected by a given current to twenty degrees, a current of double the strength will not deflect the needle a second twenty degrees, but to double the distance measured off on the tangent line.

This instrument is very useful in testing overhead lines, or measuring resistances by substitution of a known for an unknown resistance. It is much used in England as an instrument for making periodical line tests, and is employed for almost every general purpose in this country. A modification of the tangent galvanometer was constructed by Mr. Gaugain by suspending the magnet eccentrically at a point in the axis of the coil distant from the centre by half the radius of the coil. It is, however, proved by Clerk Maxwell that this modification is in reality the reverse of an improvement. The instrument was really improved by Helmholtz, who placed two equal, parallel, and vertical coils, one on each side of the needle, each at a distance from it equal to half the common radius. The proper deflection to work with is from thirty to fifty degrees. If a less deflection is used a small error in reading off makes a large one when worked out; and if a larger deflection than fifty degrees is used a large alteration in resistance will produce but little effect on a galvanometer.

Care must be taken, using this instrument, to have the scale in proper position, so that the ends of the pointer stand over the zero-points. If the deflection be too low when testing, try one of the other coils until a proper deflection is found, always taking care to use the coil which most nearly approximates the resistance to be measured.

If one coil gives too high a deflection and the next one too low, vary the battery power. This instrument is generally used with a table of tangents, so that when the needle is deflected to any degree, and the result is read off, the tangent of that degree may be ascertained by reference to the table.

The Western Union Telegraph Company uses a very good tangent galvanometer, which is shown in Figure 45.

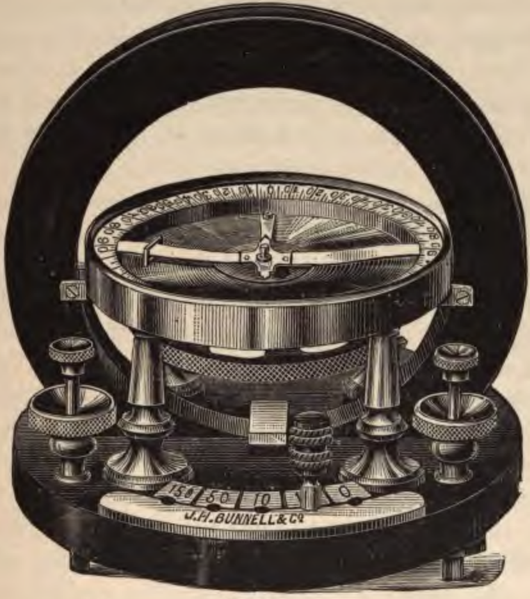

Fig. 45.

This instrument is mounted on a circular hard-rubber base, $7\frac{3}{8}$ inches diameter, provided with levelling-screws and anchoring-points. The galvanometer consists of a magnetized needle $\frac{7}{8}$ inch in length, suspended at the centre of a ring, 6 inches in diameter, containing the coils. The coils are five in number, of the resistances 0, 1, 10, 50, and 150 ohms. The first is a stout copper band of inappreciable resistance; the others are of different-sized copper wires carefully insulated. Five terminals are provided, the plug-holes of which are marked respectively 0, 1, 10, 50, and 150. The ends of the coils are so arranged that the plug inserted at the terminal marked 150 puts in circuit all the coils; at the terminal marked 50, all except the 150-ohm coil; and so on, till at the zero terminal only the copper band is in circuit.

Fixed to the needle, which is balanced on jewel and point, is an aluminum pointer at right angles, extending across a five-inch dial immediately beneath. On one side the dial is divided into degrees; on the other it is graduated, the figures of the scale corresponding to the tangent of the angles of deflection.

This galvanometer is made by J. H. Bunnell & Co., of New York, from whose pamphlet we quote the foregoing description.

104. *What is a sine galvanometer, and how is it used?*

A sine galvanometer is one in which the coils are made movable, so as to be capable of revolving on the axis around which the needle turns. A scale graduated with degrees is attached to the coil, so that the angle through which it is turned can be observed. When the needle is deflected by a current passing through the coil, the coils are turned by hand, following the needle in its deflection; as the coils are turned the needle diverges still more, but the angle it makes with the coils becomes less and less, until at length a point is attained at which the needle remains parallel with the coil.

When this point is reached the influence of the earth's magnetism exactly balances the deflective force of the current.

The strength of the current that produces the deflection will then be directly proportional to the *sine* of the angle through which the coil is turned.

The sine of any number of degrees is that part of the diameter of a circle which is included between a line drawn from its centre to the zero-point of the graduation circle, and another line, parallel to the first, cutting the circle at the degree whose sine is required. If a current of known strength, then, deflects the needle to an angle of thirty degrees, and the current to be compared deflects the needle to an angle of forty-five degrees, the strength of the second current is to the first as the sine of forty-five degrees is to the sine of thirty degrees. The usual practice is to read off the degree and refer to a table of sines for the required sine. In using the sine galvanometer it is necessary to be careful that, if the needle is at zero at starting, it is brought back exactly to zero again. It is a very accurate instrument, if properly managed, and is used chiefly for measuring and comparing weak currents.

105. *What is a differential galvanometer, and how is it used?*

It is an instrument invented by M. Becquerel. The needle is poised or suspended like that of the sine and tangent galvanometers, but is surrounded by a coil composed of two wires of equal length, size, and conductivity.

The ends of these coils are so connected that a current made to traverse them passes through the two coils in opposite directions, and therefore, when the current in each coil is equal, the effect of one coil is completely neutralized by that of the other, and the needle is not deflected. If now one current be made stronger than the other the balance will be destroyed and the needle will be moved by the stronger current.

This instrument is used to measure resistances by comparing them with standard resistance-coils. The resistance to be measured is inserted in the circuit with one of the galvanometer coil-wires, and the standard resistance in circuit with the other coil-wire. The standard resistance is usually inserted by drawing out plugs, or, as it is technically called, "unplugging resistance." We will suppose that a telegraph line is to be measured for conductivity resistance: it is placed in circuit with one of the galvanometer coils, with the effect, of course, of greatly increasing the resistance on that side; and, in consequence, a large proportion of the current returns through the other side, where as yet there is only the resistance of the galvanometer-coil, the needle being strongly deflected. We then unplug resistance from the rheostat on the opposite side to that of the resistance to be measured, until the needle is balanced; and the amount thus unplugged equals the resistance to be measured.

In order that widely differing resistances may be balanced, one coil is provided with shunts. These, when used, vary the sensibility of the galvanometer, and, by diverting a portion of the current, permit a small resistance on one side to balance a large resistance on the other. For example, if we have a resistance to be measured, and the comparison-coils at hand are not large enough to be substituted for the unknown resistance without the use of a shunt, we employ a shunt of, say, one-ninety-ninth of the resistance of the galvanometer-coil. The current passing through that coil will then be one-hundredth of the original current, because the ninety-nine hundredths pass through the lesser resistance of the shunt. Now, as the current passing through the coil is but one-hundredth part of the entire current which, if unshunted, would pass through it, it follows that the resistance which must be unplugged to balance the unknown resistance will actually be but one-hundredth part of the resistance required.

After using the shunt of one-ninety-ninth, then, we will suppose that, to balance the needle, we have to unplug five hundred ohms, which is, as stated above, just one-hundredth part of the true unknown resistance.

All we then have to do is to multiply the five hundred by one hundred. and the result is equal to the unknown resistance—that is, fifty thousand ohms.

It is particularly important that each coil should be perfectly insulated from the other, as imperfect insulation is the worst defect a galvanometer of this class can have.

106. *Describe Thomson's reflecting galvanometer.*

Thomson's reflecting galvanometer is the most sensitive instrument in use, and is almost invariably employed when very high resistances have to be measured, and also when great accuracy is required. Its principle is that of delicately suspending a very light and small magnetic needle within a coil consisting of the greatest possible number of turns of wire, and of magnifying the movements of the needle so surrounded by a beam of light, reflected from a small mirror fixed to the needle, on a graduated scale about three feet away.

Figure 46 shows the instrument in side elevation, including the lamp and graduated scale, the galvanometer being in section.

Figure 47 is a cross-section through the coils, showing the needle.

As usually made it has two circular coils, R, separated from one another by a brass frame, B, in which the needle, A, is suspended; the coils completely surround the needle, so that, no matter what angles they are deflected to, they are always under the influence of the coils. The instrument is generally made astatic, and the two needles are connected one with the other by an aluminum wire. Its base is usually made of ebonite, and is provided with spirit-levels at right angles to each other, so that the whole instrument can be set accurately level by means of levelling-screws.

Although the coils are in a brass case, they are wound on bobbins of non-conducting material. The magnetic needles are very small, usually not more than three eighths of an inch long, and to the one in the uppermost coil, if an astatic combination is used, is fixed a very small mirror, *a*. The needle and the mirror are suspended by a silk fibre from an adjustable screw, *b*.

The beam of light before mentioned is thrown from a lamp, E, placed behind a screen, Y, and falls on the needle-mirror, which is slightly inclined so as to reflect on a graduated scale, I, fixed on a stand, F, the said scale being placed immediately above the point where the beam leaves the lamp.

The scale is a straight and flat surface, and is generally marked with three hundred and sixty divisions on each side of the zero-point.

The galvanometer-coils are insulated from the frame by a disc of hard rubber, T.

In the best forms of instrument a glass shade is placed over the coils, and from the centre of its top a brass rod rises. A short brass tube slides on the rod and carries a weak bar magnet, slightly curved, which is fixed at right angles to the rod. This magnet can be slid up or down, or twisted around, and the sensitiveness of the needle thereby increased or diminished. By turning the bar magnet so that its north pole points to the north, it will act on the needle with a magnetism opposing that of the earth, and tend to turn the needles around. By sliding the bar gradually down a point is reached where the earth's magnetism is just counteracted. When this point is arrived at the needle will stand at any position. The regulating magnet is then raised about an inch higher than the neutralizing position, when the earth's magnetism will be just sufficient to keep the needles north and south. They are, therefore, very sensitive to any external force, and move when a very weak current passes through the coils.

In using this instrument no iron must be near it, and the testing operator should remove any keys or knives from his person, as so sensitive an instrument is often affected by such bodies.

These instruments, when intended to measure large resistances, are often wound with German-silver wire, and their own resistance is sometimes as high as fifty thousand ohms.

Such an instrument will give, with one cell of Daniell's battery, a deflection of two hundred divisions when measuring an outside resistance of ten million ohms.

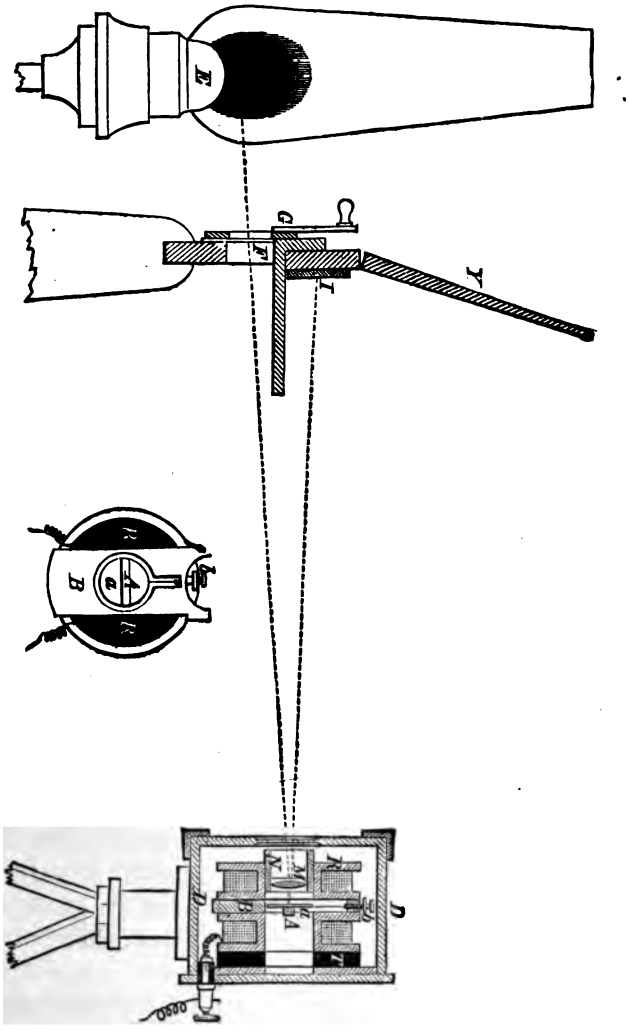

Fig. 46.

Fig. 47.

The reflecting galvanometer, besides being used for delicate measurements and high resistances, is much employed as a receiving instrument for telegraphic signals sent through long submarine cables. A modification, known as Thomson's marine galvanometer, is used on ships laying cables, as a testing instrument, and for similar purposes. It is so arranged as not to be affected by the oscillations of the vessel, the fibre carrying the needle being attached to both top and bottom of the frame in which it is suspended.

107. *What is the Wheatstone bridge?*

The Wheatstone bridge, though usually classed with galvanometers, and explained under that head by most of the text-books on electricity, is, strictly speaking, not a galvanometer, but a system of measurement, or an arrangement of circuits whereby a galvanometer can be most advantageously employed. It was devised by Mr. S. Hunter Christie, and described by him in the *Philosophical Magazine* in 1836. But it was not much noticed or used until introduced by Wheatstone in 1843, in a paper forwarded to the Royal Society describing several new instruments for electrical measurements. Although previously described by Christie, it is almost universally known as Wheatstone's bridge or balance. It is usually represented as in Figure 48, by a diagram with the wires arranged in the form of a lozenge.

The lozenge is composed of four wires, which, for convenience, we will call A, B, C, and D. Two of the opposite corners of the lozenge are connected by a wire with a galvanometer in circuit, and the other two opposite corners are respectively connected to the two poles of a battery. The ires which converge to a point at the left hand we

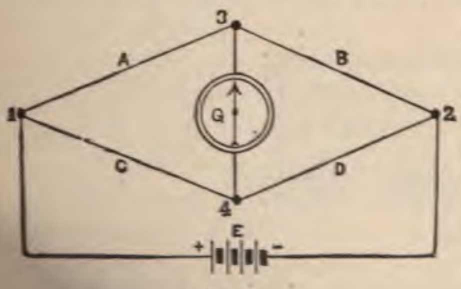

Fig. 48.

will call A and C, and the two that converge to the right hand we will call B and D.

Adjustable resistances are inserted in the branches A and C, a comparison coil, or rheostat, in one of the branches B D, and the resistance to be measured in the other.

When all of the resistances are equal and the battery circuit is closed the galvanometer on the cross-wire will not be affected; because, as electrical currents are caused by a difference of potential, and the two points connected by the galvanometer are, under those circumstances, at the same potential, it is obvious that no current will pass through the cross-wire and galvanometer, there being no force tending to cause a current therein.

Again, when branch A bears the same proportion to C that B does to D, no current will pass on the cross-wire, because the battery current having divided at the point of divergence of the wires A and C, in inverse proportion to the several resistances of those branches, that proportion of the current which is in each branch, on arriving at the crossing-point of the bridge, will still be at the same potential.

But if the resistance A does not bear the same proportion to C that B does to D, the needle will be strongly deflected. Hence it will be readily seen that unknown resistances can be accurately measured by inserting them, for example, into the branch D, and varying the other resistances—chiefly that in the branch B—until the needle stands at zero. The proper proportion is now restored, and the unknown resistance is ascertained by a simple calculation in proportion, or the rule of three. For instance, we will suppose that in A we have a resistance of 100 ohms, in C 10 ohms. We then insert our unknown resistance in D, and a rheostat or resistance-box in B. When we close the battery circuit the needle deflects. We then vary the resistance in the box until the needle remains at zero. To obtain this result we have unplugged 200 ohms. There fore, as 100 is to 10, so is 200 to 20—the resistance required.

This is merely given as an illustration of the system. In practice, to measure a resistance within the range of the rheostat, the resistances in the branches A and C are made equal, because when they are equal the galvanometer is most sensitive. But, as it will readily be seen from the foregoing example, resistances both of extremely great and extremely small magnitudes can be measured by this system.

The bridge apparatus generally embraces a rheostat and galvanometer with two keys, one to make and break the battery circuit, the other to make and break the bridge wire. The rheostat usually is made with the resistances of the three arms A, C, and B all in one box, and with the branches A and C each consisting of three coils—10, 100, and 1,000 ohms respectively—any of which may be used by the withdrawal of its short-circuiting plug. The arm B is a set of resistance-coils varying from 1 to 4,000 or 5,000 ohms, while the arm D is provided with two binding-screws for the reception of the resistance to be measured. Circuits which only have one end within reach can be measured by putting one pole of the battery to earth, the branch B also to earth, and extending the branch D to the circuit to be measured, which must also be grounded at the distant end. In using this apparatus, when the resistance to be measured is approximately known, the proper plugs must be first taken out of A and C; the battery key should first be pressed, then the galvanometer key, making very short contacts with the latter, until the needle is nearly balanced. When the balance is obtained it should be ascertained whether or not the needle will remain steady when the contact is made and broken.

Almost any good galvanometer can be used with the system of measurement. The bridge is not now ly used for measurements, but has been utilized also in duplex telegraphy and in the construction of sensitive burglar-alarm telegraphs.

108. *What is meant by the constant of a galvanometer?*

The *constant* of a galvanometer means simply the deflection of the galvanometer-needle, obtained through a standard resistance by a standard battery. The expression is used more frequently in England than in America; and there, as explained by Kempe, the term constant is applied to "the product of the deflection in degrees, and the resistance in ohms, when multiplied together. For example: With a battery, a galvanometer, and a resistance of 1,000 ohms in circuit, a deflection of 20 degrees is obtained. The 1,000 is then multiplied by the 20, and the product, 20,000, is called the constant."

If wires are to be tested the constant is first taken, as above, after which the wires are inserted in circuit, one by one. To obtain the results in ohms the constant is divided by the deflection obtained from each.

109. *What is a rheostat? To what apparatus is the name now applied? How is it used?*

The name rheostat was originally given by Wheatstone to an instrument devised by himself for the purpose of varying at will the amount of resistance in a circuit.

Two cylinders, one of metal and the other of some non-conducting material, were arranged near each other, so that a fine German-silver wire could be rolled and unrolled from one to the other, the resistance of the wire being known. When the fine wire was all rolled on the metal cylinder it had no appreciable resistance, as the current would travel through the mass of the roller; but when the wire was wound on the wooden or rubber cylinder in grooves prepared for it, the current was forced to pass through the entire length of the wire unrolled. By this means resistance was added to or taken from the circuit. This apparatus is now scarcely ever used, but the name survives, and at the present day when we speak of a rheostat we mean a set of standard resistance-coils arranged together in a box and used for electrical measurements. Such an apparatus is show in Figure 49.

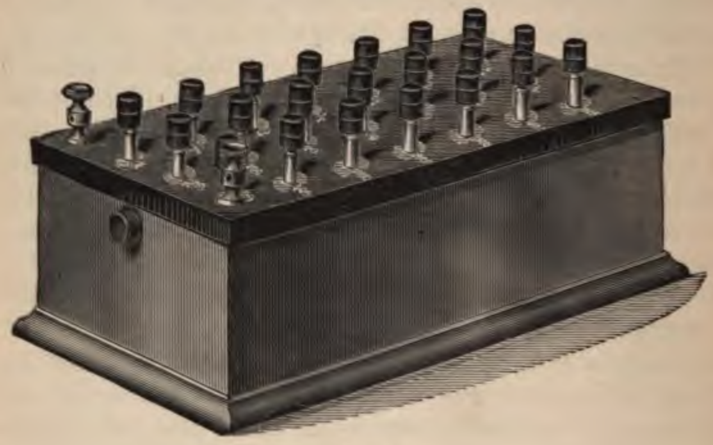

Fig. 49.

Coils of wire, varying in resistance—for instance, from $\frac{1}{10}$ of an ohm to 5,000 ohms—are arranged in a box, their terminal wires being permanently connected together by a series of stout brass plates on the ebonite cover of the box. Conical brass plugs, inserted between the brass plates, serve to throw the coils in and out of circuit.

When all the plugs are in, and the resistance-box is in circuit, the current takes the short path through the brass plates and the plugs; but when any plug is withdrawn the short route between the two brass plates which that particular plug connected is broken, and the current is consequently forced through the coil below, and the resistance of that coil is added to the circuit. It will thus be seen that, by varying the arrangement of e plugs, the resistance may also be varied almost in- tely. In making a box of resistance-coils thick uld be used for the small resistances, for two reasons: first, they are easier to adjust; and, secondly, they are less likely to become deranged by powerful currents.

The wire used must be of some metal which is not easily affected by changes of temperature. German silver is generally used.

The wire is insulated by two coatings of silk, and is wound double so as to eliminate self-induction, and also that it may not affect galvanometers in its vicinity. When coiled the bobbins are soaked in melted paraffine, which maintains their insulation. The high resistances are made of fine wire, in order to economize space.

The following precautions are necessary in using resistance-coils: Keep the brass plugs clean and bright; because, if dirty, they will not entirely cut out the coils. When a plug is inserted do not simply push it in the hole, but give it a twist, and thereby insure good contact. Before commencing to use a rheostat give all the plugs a twist, to be sure that none of them are loose; and, finally, touch the brass plugs as little as possible with the fingers.

110. *Give some simple methods of measuring resistance.*

The earliest method of measuring resistances was by using a common galvanometer multiplier, or a sine or tangent galvanometer, to place the resistance to be measured in circuit alternately with a standard resistance. If the deflection remained the same in both cases, it was assumed that the resistances were equal. The difficulty in this method was that the electro-motive force and internal resistance of the battery were supposed to remain constant—a condition which they rarely fulfil. The desire of obviating this difficulty was the cause of the introduction of the differential galvanometer and Wheatstone bridge, in both of which instruments the result is attained irrespective of battery variation. The differential method was much used by Becquerel and others at one time, but it is entirely superseded in England by the bridge method. In the United States the method that happens to be most convenient at the time is generally used. As the rheostat is now often made with a switch that can be instantly moved from the standard resistance to the resistance which is to be measured, the objection to the substitution method is substantially removed.

To measure resistance by any ordinary galvanometer, using resistance-coils, we must first connect up the galvanometer in circuit with the resistance to be measured and a battery sufficient to produce a good deflection. Note the deflection produced, then substitute the rheostat for the unknown resistance, and unplug resistance until the needle shows the same deflection as before. Add the figures on the holes unplugged, and we have the required resistance. If we use the rheostat provided with the switch, all we have to do is to throw over the switch, and we can verify the result by moving the switch quickly a number of times. If the needle stands still at the same deflection, whichever side the switch rests, the result is correct. In using a differential galvanometer we connect the rheostat on one side and the unknown resistance on the other, and vary the resistance in the rheostat until the needle stands at zero. The resistance unplugged equals the resistance required.

In using the Wheatstone bridge system the unknown resistance is inserted in the side of the bridge, opposite to the variable resistance. If we have any idea what the resistance to be measured should be, we first unplug equal resistances on the first two sides of the bridge, each as near to the unknown resistance as may be. We then unplug resistance on the third side until the needle remains at zero when the battery key is pressed down. The resistance unplugged from the comparison-coils then equals the resistance required. For example: We have a bridge system, the first and second branches of which each possess resistance-coils of 10, 100, and 1,000 s, any or all of which may be unplugged at will;

the third branch has a series of coils, from 1 to 4,000 ohms, and the fourth has binding-posts for the insertion of the resistance to be measured. This resistance we suppose to be about 400 ohms. The 100-ohm coils in branches one and two being the nearest figures to the supposed resistance, we unplug them, and, pressing the battery key, find that the needle violently deflects. We then unplug 400 ohms on branch three, and again press the battery key, when we find that the needle still deflects slightly. We unplug 50 ohms more, and find the needle has now passed the zero-point and deflects to the opposite side, showing that we have unplugged too much. We replace the 50-ohm plug and draw 20. The needle will now, perhaps, stand at zero when the key is pressed, showing that the resistance required is 420 ohms. The reason for withdrawing the 100-ohm coils on the first and second branches is that the galvanometer is most sensitive when all the branches are equal. It is, therefore, as sensitive as possible when the branches are as nearly equal as possible.

When we measure the resistance of a wire the distant end of which is to earth, we join the near end of the wire to the terminal of branch four, put one end of the battery to earth, and also put the terminal of branch three to earth, and proceed as before.

111. *How may three parallel line-wires be measured without using an earth-wire?*

Call the wires 1, 2, and 3. The resistance of each is required; 1 and 2 are connected at the distant end, and the loop measured, the result being, we will say, 300 ohms. We then connect 1 and 3 at the distant end, and, measuring, find the result to be 600 ohms. Lastly, we loop 2 and 3, and, measuring again, find the resistance to be 700 ohms. To get the resistance of No. 1 we add the first two results together—the 300 and the 600 ohms—the sum being 900, which is obviously the sum of the resistances of all the wires; the first being doubled, as it was measured twice. We then subtract the third result from the sum so obtained, deducting 700—the amount of resistance of Nos. 2 and 3—from 900, and find the remainder to be 200. This divided by 2, because No. 1 was twice measured, gives us 100 ohms as the resistance of No. 1. The resistance of No. 2 is ascertained similarly—that is, by adding the first and third results, subtracting the second, and dividing by 2, and is then found to be 200 ohms. The resistance of No. 3 is ascertained by adding the second and third results, subtracting the first from the sum, and dividing by 2, leaving the final result 500 ohms. That these final results are correct may, of course, be readily proved by adding them together.

112. *What is meant by the internal resistance of a battery?*

It must not be forgotten that the battery is a part of the circuit, and must therefore be considered not merely as a producer but also as a conductor of the current. Considering it in this light, it is obvious that it must of necessity bear its proportion of the resistance of the circuit, since, as previously stated, all substances present more or less resistance to the passage of electricity. The internal resistance of a battery consists, first, of the resistance of the liquids, and, secondly, of the porous cell, if one is used, to separate the liquids.

It is modified by the size of the plates, for the larger the plates are, the greater the area of the liquid, and consequently the less its resistance; by their distance from each other, for the nearer they are placed the shorter is the liquid conductor; and by the nature of the liquid in which they are immersed, for acid solutions usually offer much less resistance than saline liquids.

Both acid and saline solutions, though the best of liquid non-metallic conductors, offer enormously more resistance than metals, as will be seen from the following comparison:

If the resistance of copper be taken as 1, mercury may be taken as 50, a solution of water twelve parts and sulphuric acid one part will be 1,500,000, a solution saturated with zinc sulphate 16,000,000, and a saturated solution of copper sulphate 17,000,000.

The resistance of a battery having its cells arranged in series increases in direct proportion to the number of cells which compose it—that is, if one cell have an internal resistance of 1 ohm, a battery of 10 similar cells will have a resistance of 10 ohms.

If the two poles of a battery are connected by the shortest and thickest wire practicable, the internal resistance of the battery constitutes, practically, the entire resistance of the circuit.

The voltaic battery is, therefore, a type of all force-producing machines, in that it produces force and at the same time offers a resistance to that force; as, for instance, in a steam-engine the friction of the steam in the pipes, of the piston in the cylinder, and of the shafts in the bearings cannot be avoided.

The internal resistance of some of the cells in common use is given below:

Grove, half an ohm; Daniell, 3 to 5 ohms; gravity, 2 to 4 ohms; Leclanché, about 1 ohm; Minotto, 10 to 20 ohms.

113. *Describe the simplest and best methods of measuring the internal resistance of a battery.*

There are various methods of determining the internal resistance of a battery. We give three ways which are as simple as any. The first, often called Mance's method, from its discoverer, is to place the battery to be measured in the fourth branch of a Wheatstone bridge. Let the first two branches be fixed resistances, and the third a rheostat or adjustable resistance. The galvanometer is kept in the usual place on the cross-wire, but in the usual place of the battery we substitute a key, which permits us to connect or disconnect the wires, thereby enabling us to close or open the circuit at the point where the battery is generally placed. The adjustable resistance is then varied until the making and breaking of contact by the key does not alter the deflection of the needle. Then, as the resistance in branch

1 of the bridge is to branch 2, so is the resistance unplugged from the rheostat in branch 3 to the internal resistance of the battery in branch 4; or, if the two branches at the first end are made equal, the resistance of the battery is also equal to that of the rheostat.

To illustrate: We will call the four branches of the bridge A, B, C, and D, and have a resistance of 10 ohms in each of the branches A and B. We place the battery to be measured in D, and the rheostat in C. We then close the key and the needle deflects; but on raising the key the deflection alters materially. We unplug, say, 50 ohms from the rheostat, and find then that the deflection remains the same, whether we depress or raise the key. Then, as A and B are equal, both being 10 ohms, D must also be equal to C—that is, 50 ohms. This method is practically independent of the galvanometer resistance, and is extremely accurate, because it is not affected by variations in the strength of the battery.

As in measuring the resistance of a galvanometer by its own deflection, it will generally be necessary to adopt some method of reducing the deflection, in order to obtain an accurate measurement. This may sometimes, when the instrument is not very sensitive, be done by making the branch resistances unequal. The desired end may be gained more effectually by shunting the galvanometer.

In the second method the tangent or sine galvanometer may be used. Connect a rheostat, a tangent galvanometer, and the battery to be measured in circuit together. Vary the resistance in the rheostat till the needle shows a deflection, for example, of 45 degrees. Then, referring to the table of tangents, we find that the tangent of 45 degrees is 1. Note the resistance unplugged and find what half of the tangent of the deflection is. In this case, as the tangent is 1, its half will be, of course, one half, or, in decimals, .5. Referring again the table, we see that the degree of which .5 is the tangent is 27. Then unplug resistance until the deflection is reduced to 27. Again note the resistance unplugged. Then, to ascertain the battery resistance, double the smaller resistance noted and add to the result the resistance of the galvanometer, and subtract the total from the larger resistance. The difference is the resistance of the battery. For example: We use a galvanometer of 100 ohms resistance, and unplug for the first deflection 80 ohms. To halve the tangent of the first deflection we have to unplug 400 ohms. We then double the smaller resistance, the result being 160 ohms, to which we add the resistance of the galvanometer, 100 ohms, making in all 260. Then we subtract 260 from the larger resistance unplugged, 400 ohms, and find that the difference is 140, which is the resistance of the battery.

A third method is to join two cells of the battery whose resistance is to be measured in opposition to one another, so that they send no current of their own, and then measure the two together by a tangent or differential galvanometer, in the same way that we would measure any other resistance.

The resistance of a single cell will be half of the two.

114. *How is the resistance of a galvanometer ascertained?*

If we have more than one galvanometer at hand the obvious way of ascertaining the resistance of either is, of course, to regard them as any other ordinary resistance to be measured, using one of them as an instrument with which to measure the other. But circumstances sometimes occur which render it desirable that we should know the resistance of the galvanometer which we are using when we have no other to use as a measuring instrument. There are several ways whereby this may be accomplished. The two simplest are here given: First, using the Wheatstone bridge. The galvanometer is placed in one of the branches of the bridge—branch 4, for instance—instead of being left in the cross-wire circuit as usual; and in the regular place of the galvanometer a circuit-closing key is placed, so that we may connect or disconnect the two points which would ordinarily be connected to the galvanometer. The battery is retained in its regular position; and, of course, the current flowing from it passes through the branches of the bridge and causes the galvanometer-needle to deflect.

The coils in the other branches are then adjusted until the deflection remains unaltered, whether the key in the cross-wire is depressed or not. When this is the case a balance has evidently been effected, and consequently we get the resistance of the galvanometer by the usual proportion; thus, as branch 1 is to branch 2, so is the resistance of branch 3 to the resistance of the galvanometer in branch 4. To illustrate: If we have 100 ohms unplugged in branches 1 and 2, and to effect a balance we have to unplug 250 ohms, the first two branches being equal, the galvanometer in branch 4 is also equal to the amount unplugged in branch 3—that is, 250 ohms. That this method may be clearly understood, we must go back for an instant to the principle of the bridge.

We will see that if a balance is not established, and a current is flowing in the coils of the galvanometer, which is in its usual place in the cross-wire circuit, the current will be denoted by the deflection of the needle; and, as a matter of course, any change in the resistance of the galvanometer, or of any part of the cross-wire, will affect the strength of current in all of the four branches of the bridge. If, on the contrary, a balance *is* established, and the fact is indicated by the needle remaining undeflected, we may alter the resistance of the galvanometer, or even take it away altogether, without in any way affecting the current in the branches.

So, in measuring the resistance of the galvanometer by this method, when equilibrium is once attained, it matters not whether the key in the cross-wire is open or closed, the deflection remains stationary.

It will be observed that this measurement is identical nciple with one of the plans of measuring the internal resistance of a battery. As described in that method it frequently happens that the deflection of the needle is so great as to be immeasurable, and one of several expedients must be adopted to reduce it.

This may be done by giving the needle an initial bias to one side by means of a permanent bar magnet, or, what is equivalent, bringing the needle back to zero by approaching the permanent magnet to it.

Or we may shunt the galvanometer by a shunt of sufficiently low resistance to bring the needle to a proper deflection, and then measure the joint resistance of shunt and galvanometer.

Or we may shunt the battery, so that but a small part of the current passes through the galvanometer.

Or we may weaken the battery current by inserting high resistance in the battery circuit.

Or we may insert resistance in the same arm as the galvanometer, and, measuring the whole as one resistance, deduct the amount of the added resistance from the total to give the resistance of the galvanometer.

The second method may be adopted when the bridge cannot be used, and is as follows: Put the galvanometer in circuit with a resistance-box and a battery whose internal resistance is so small that it may be neglected; unplug any resistance, say 400 ohms, and note the deflection. We will assume it to be 20 degrees. Then put plugs back, withdrawing resistance from the circuit until the former deflection is doubled, so as to reach 40 degrees, there being then 300 ohms unplugged. Then multiply the two resistances by their respective deflections, subtract the smaller product from the larger, and divide the result by the difference between the two deflections. Thus, 400 ohms multiplied by 20 is 8,000; and 300 multiplied by its deflection 40 is 12,000. Then 12,000 minus 8,000 leaves 4,000. That amount divided by 20, which is the difference between the deflections 20 and 40 degrees, gives us, as the resistance of the galvanometer, 200 ohms.

115. *How may the electro-motive force of batteries be measured, compared, or estimated?*

The electro-motive force of a voltaic battery may be determined by several methods, but as no absolute standard of electro-motive force is known we cannot determine the force of any particular battery in standard units (volts), but can only compare the relative force of two or more batteries. We will consider several of the most simple and reliable methods:

First. If we join up a number of cells in circuit in opposition with a number of other cells and a galvanometer, by adjusting the number of cells so that no current passes, and that, consequently, the needle has deflection, the relative force of the two batteries may be determined.

For example: We desire to know the electro-motive force of a chromic-acid battery of 10 cells, and we have a Daniell battery with which we can compare it. We know that a Daniell cell in good order is about 1.079 volts. We connect one pole—the zinc, for instance—of our chromic-acid battery to one terminal of the galvanometer, and the carbon pole to the copper pole of a battery composed of an equal number of Daniell cells; the zinc pole of the Daniell battery is connected to the other terminal of the galvanometer. We then find that the chromic-acid battery causes the needle to deflect. We add cells to the Daniell battery until the needle deflects no longer. We find that we have added 10 cells. Thus it has taken 20 Daniell cells to balance 10 of the chromic-acid cells, showing that the chromic-acid battery has just twice the electro-motive force of the Daniell, or in the ratio of 2 to 1.

To ascertain the value in volts multiply the electro-motive force of the Daniell cell, 1.079, by the number of cells, 20, and divide by the number of acid cells, 10. The quotient is 2.158, which is the value of the chromic-
d cell; or, in other words, as the larger number of
s to the smaller number, so is the electro-motive

force of the larger number, in volts, inversely to that of the smaller number.

The *second* method, using a tangent galvanometer, is as follows: The electro-motive forces of two batteries, which we will call No. 1 and No. 2, are to be compared. No. 1 is joined up in circuit with a galvanometer and a resistance-box. Sufficient resistance is unplugged to cause a convenient deflection of the needle. The tangent of the deflection must be noted, as must also the total resistance in circuit—that is, the resistances of the battery, galvanometer, and that unplugged from the box. Then remove battery No. 1 and substitute No. 2. If the internal resistance of No. 2 is different from No. 1, the resistance unplugged must be adjusted until the total resistance in circuit is the same as before. Again note the tangent of the deflection. Then the electro-motive force of No. 1 is to the electro-motive force of No. 2 as the first tangent noted is to the second.

For example: Let No. 1 battery have a resistance of 60 ohms and the galvanometer 100 ohms. We unplug 800 ohms in the resistance-box, making a total resistance of 960 ohms.

With this resistance we will suppose the needle deflects to 35 degrees. Referring to the table of tangents, we find that the tangent of 35 degrees is .70.

We note the above facts and disconnect battery No. 1, substituting in its place No. 2, which has a resistance of 100 ohms. We alter the resistance-coil to 760 ohms to make the total resistance the same as before—that is, 960 ohms. We find the deflection now to be 42 degrees, the tangent of which is .90.

Then as .70 is to .90, so the E. M. F. of No. 1 is to the E. M. F. of No. 2. In these measurements it is supposed that we know the E. M. F. of one of the batteries, which is called the standard battery; so, to reduce the calculations to figures, we will call No. 1 the standard, and assume it to have a value of 20 volts; and as .70 is to 20 volts, so is .90 to $25\frac{5}{7}$ volts.

The *third* method was devised by Wheatstone, and consists in placing each battery alternately in circuit, varying resistance to produce the same deflection with each, then adding the required resistance in both cases to produce lower but, again, similar deflections; the E. M. F.s then being directly proportional to the added resistances which in both cases were required.

To illustrate: No. 1 battery, which we will suppose has a known E. M. F. of 25 volts, is placed in circuit with a galvanometer and a resistance-box. We unplug, say, 2,000 ohms, and note the deflection to be 30 degrees. Adding 200 ohms to that already unplugged brings the deflection down to 24 degrees. Taking out battery No. 1 and inserting battery No. 2, we find that to produce the same deflection—30 degrees, as at first produced with No. 1—we have to unplug but 1,800 ohms; and by adding 150 ohms we bring the deflection down to that produced by adding, when No. 1 was in circuit, 24 degrees. Now, the amount added in the measurement of No. 1—that is, 200 ohms—is to the amount added in the measurement of No. 2—viz., 150 ohms—as the E. M. F. of No. 1, 25 volts, is to 18¾ volts, the E. M. F. of No. 2.

116. *What is a shunt?*

A shunt may be defined as a contrivance for leading by another route part of a current which, as a whole, is too powerful for the immediate purpose. In the present connection it is a coil of wire used to divert some definite proportion of a current aside from or past a galvanometer or other instrument, instead of allowing it to pass through the instrument coils.

For instance, if the galvanometer has its two terminals connected by a wire which includes a resistance equal to one ninety-ninth of the resistance of the galvanometer, we reduce the galvanometer to one-hundredth of its original sensibility, ninety-nine hundredths of the current passing through the shunt and the remaining hundredth through the galvanometer. Similarly, if the shunt be exactly equal to the galvanometer the current will divide in equal proportions between the galvanometer and the shunt. If the shunt is one-half the resistance of the galvanometer, two-thirds of the current will pass through the shunt and one-third through the galvanometer, and so on. The rule is that the current divides between the galvanometer and the shunt in inverse proportion to their respective resistances, the greater portion of the current always going through the smaller resistance, and the smaller portion through the greater resistance.

When very strong currents are being used in measurements it is necessary that a shunt be employed, in order that the needle's deflections may be reduced to a reasonable limit.

Galvanometers are usually provided with three shunts, which are respectively one-ninth, one ninety-ninth, and one nine-hundred-and-ninety-ninth. These reduce the current passing through the galvanometer respectively to its one-tenth, one-hundredth, or one-thousandth part.

117. *What is the formula for finding what resistance a shunt should be to reduce the sensibility of a galvanometer to any required fractional part, and what is meant by the multiplying power of a shunt?*

The formula for finding what the resistance of a shunt should be, to give it a definite value, is to make the resistance of the shunt equal to the resistance of the galvanometer, divided by the multiplying power required, minus 1.

For example: Suppose we have a galvanometer whose resistance is 100 ohms, and we wish to prepare a shunt which will reduce the sensitiveness to one-tenth. We divide the galvanometer resistance by the fractional part to which we wish to reduce the sensibility, minus 1—that is, we divide the 100 by 10, minus 1, which is, of course, 9. The quotient of 100 ohms divided by 9 is 11⅑ ohms, which is the resistance of the shunt required, and is one-ninth of the resistance of the galvanometer. This is called a shunt having a multiplying power of 10. To obtain the true value of a deflection taken, for instance, from a shunted tangent galvanometer, we must multiply the tangent by the multiplying power of the shunt used. To ascertain the multiplying power of any shunt whose resistance is known we divide the resistance of the galvanometer by the resistance of the shunt, and add one to the quotient.

Again: We are using a galvanometer with a resistance of 100 ohms, and insert a shunt whose resistance we know to be 25 ohms. To find out by what number we have to multiply the shunted result we divide the 100 by 25, which gives us a quotient of 4, to which must be added 1, showing that 5 is the multiplying power required.

118. *If we employ a shunt of a given proportion, is the current which then passes through the galvanometer strictly the proportionate part of the original current to which it is apparently reduced?*

No; because by the act of employing the shunt we furnish a double route for the current, and thereby diminish the external resistance of the circuit, and, as a consequence, the strength of current furnished by the battery is increased. It is, therefore, the increased current that splits between the shunt and the galvanometer, instead of the original one. For example: If we are using a tangent galvanometer, and the tangent of deflection without the shunt is .80, we might naturally have supposed that, on the introduction of a shunt which reduces the sensitiveness of the galvanometer one-half, the tangent would also be brought down one-half—that is, to .40. But such is not the case, the result being some higher tangent than .40; and to bring about an accurate result we must first find the joint resistance of the shunt and galvanometer, and then insert an additional resistance in the battery circuit equal to the amount by which the original resistance was decreased. Thus, if both the galvanometer and shunt are 100 ohms resistance, the joint resistance of the two is 50 ohms.

In this case, therefore, we should have to insert 50 ohms in the battery circuit to compensate for the decrease in resistance and to bring the current back to its original strength.

CHAPTER X.

PRINCIPLES OF TELEGRAPHY EXEMPLIFIED IN DIFFERENT SYSTEMS.

119. ***What are the necessary parts of every line of telegraph, or telegraphic circuit?***

In answering this question we shall be assisted by remembering what is the work required to be done in electrical transmission.

This, we shall see, may be divided into three heads: *First.* To generate or develop the electricity in sufficient quantity and of the necessary strength to do the required work in the circuit. *Second.* To be able to transmit the electricity to any required distance without any serious loss by the way. *Third.* To cause it, on its arrival at the distant point, to produce results appreciable by the senses; in other words, to record or deliver its messages.

To accomplish these results, then, it is necessary to have in each telegraphic circuit, as shown in Figure 50—

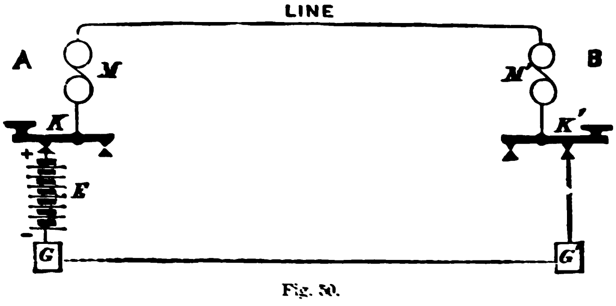

Fig. 50.

(1) A generator of electricity, which in nearly every case is a galvanic battery, E, but which may be, and sometimes is, a magneto or dynamo-electric machine.

(2) A conductor of electricity between the stations and B, consisting usually of an insulated line-wire

extended from one terminal station to the other, and ending in the ground, G, at each terminal.

For practical purposes the earth may be regarded as a return wire. When the line is a short one a return wire is often actually used, and is indeed preferable, as the earth connections frequently interpose a higher resistance than a short return wire.

(3) At each station apparatus to render the current evident to the senses—that is, instruments, M and M′, wherewith to receive the signals and to interpret them, and corresponding instruments, K and K′, by which they are transmitted.

These elements—*i.e.*, the battery, the line-wire, the transmitting and receiving instruments at each station, and, finally, the earth—compose the telegraphic circuit.

120. *Have any attempts been made to utilize frictional electricity for telegraphic purposes ?*

Yes, in several cases. The first attempt on record is that of Lesage in 1774. He employed twenty-four wires, one for each letter in the alphabet, each wire terminating in a pith-ball electroscope, tagged with its respective letter. Then Lomond, in the year 1787, employed one wire, with a pith-ball electroscope. In the same year Betancourt used one wire, operated by a Leyden-jar battery. The next attempt was made by Reizen in 1794. He arranged twenty-six wires. The letters were cut out in tin foil and rendered luminous by the passage of the electric spark. In the next year Cavallo used one wire, and the number of sparks designated the different signals ; two hundred and fifty feet was, however, the extreme length of line he used. In 1796 D. F. Salva, of Spain, is said to have worked a telegraph through a line of twenty-six miles.

In 1816 Ronalds laid wires both underground and in the air, and used a pith-ball electroscope hung in front of a clock, which enabled the letters on a dial to be read off. Finally, Harrison Gray Dyar, an American, constructed a telegraph on Long Island, in 1827 and 1828, which was to represent the different letters by means of the difference in time between the several sparks. In all these systems frictional or mechanical electricity was intended to be employed. These early attempts in electric telegraphy, valuable as successive steps in the art, were all failures, chiefly from the fact that frictional electricity, from its high potential, or, in other words, its great power of overcoming resistance, escapes from the line of communication over even the poorest conductors.

121. *What systems of commercial telegraphy are in use at the present time?*

In America the telegraphs now in general use are:

1. The Morse, with its improvements of duplex, quadruplex, and harmonic telegraphy; its use is universal.

2. The type-printing telegraph, used chiefly on trunk lines between Boston and New York, New York, Philadelphia, and Washington, and New York and Chicago.

3. The Wheatstone automatic system.

In nearly every country the Morse system is most generally used, and maintains its supremacy on account of its simplicity, its comparative accuracy, and the speed with which it may be manipulated.

The Wheatstone needle system is still employed on many circuits in England, but is being gradually superseded by the Morse.

Its use is advocated by English telegraphic authorities for circuits which have many stations, none of which singly do much work, but which collectively have enough business to occupy a wire, and for railroad service. The maintenance of the needle system is economical.

A magneto-dial system, called the Wheatstone A B C, is also extensively employed there, and is especially adapted for branch lines and offices in small villages where there is not enough work to pay for an expert operator. The Wheatstone automatic is also much used.

Indeed, England has been most successful in automatic telegraphy.

122. *Give a brief outline of the American closed-circuit Morse telegraph system.*

A number of stations, each provided with main-line instruments, consisting of a key and relay, together with local circuit instruments, consisting of a sounder or register and a local battery, are placed on one main circuit together. The main line may be of any desired length within certain limits, but is not ordinarily more than two or three hundred miles long. The two end stations are called the terminal stations, and at these the main batteries are usually located. Should it take three hundred cells of battery to work the line, about half should ordinarily be placed at each end. In that case, if at one terminal station the copper pole of the battery be to line, at the other terminal station the zinc pole must be to line; and the circuit, starting, we will say, at station A, at the ground, will pass through the battery of

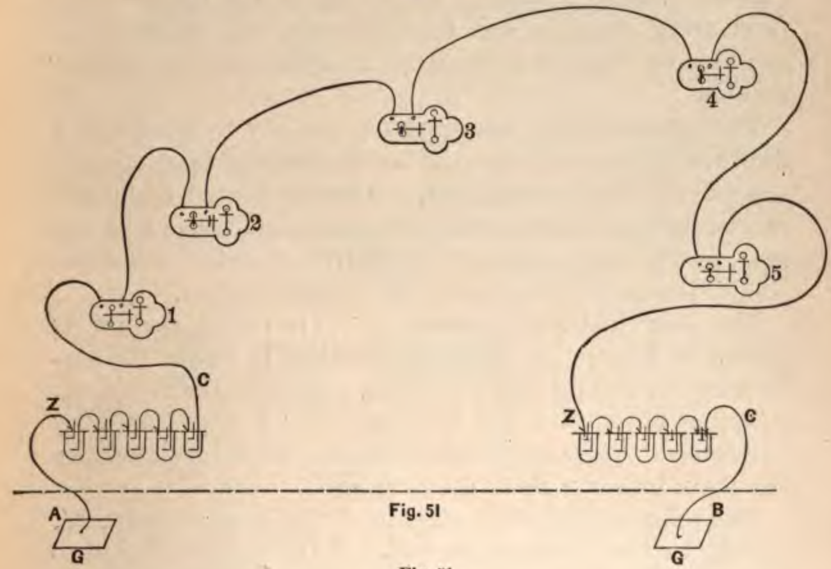

Fig. 51.

one hundred and fifty cells, entering at the zinc pole, leaving the copper pole for the line.

Thence its route is from station to station, at each one passing through the spools of the relay and the key, until it arrives at the distant terminal, station B, where, after passing the relay and key, it enters the battery at the zinc pole and finally leaves its copper pole for the earth. A great number of stations may be included in this main circuit, and all the instruments will work simultaneously in unison with each other when a key is operated at any station. This arrangement is clearly shown in Figure 51.

Should an operator at any office wish to send a message to any other office, he must open his key, thus breaking the circuit and causing the current to be interrupted. The armature of each relay in the circuit then falls away, opening the local circuits and causing the sounder or register armatures to respond in a similar manner.

The operator then manipulates his key by alternately depressing it and allowing it to rise so as to form the letters of the Morse alphabet. The armatures of all the relays and sounders in the circuit respond to each of his movements, and so convey the desired signals throughout the entire circuit, including the distant station.

The electrical arrangement of a terminal station is shown in Figure 52, in which the line, L, enters the station by the lightning-arrester, X, passes to the relay, M, which it enters by the binding-screw 1 and leaves by the screw 2, proceeds to the key, K, and from thence by the main battery, E, to the ground G.

The relay operates the circuit of the local battery, E′, which, leaving the positive pole of the battery, is led to screw-post 3 of the relay, through the armature and circuit-closing points of the same to screw-post 4, out to the sounder, S, and from thence back to the negative pole of the local battery.

The arrangement of a way station is quite similar, differing only in the fact that the main wire, after passing the relay and key, instead of going to the main battery and ground, leads out to the next station. A cut-out is necessary at way stations.

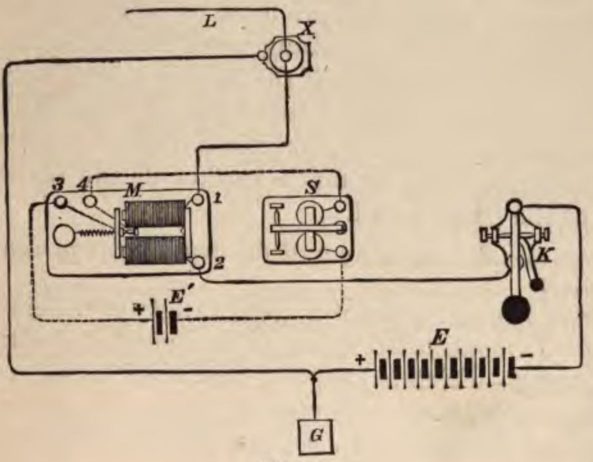

Fig. 52.

The way in which the local circuit is controlled by the main line is illustrated by Figure 53, where a relay, M, in a main-line circuit is shown, provided with an armature and lever, S. This forms part of the circuit of a local battery, B, which passes through the relay-points, P, and sounder-magnet, G; the points actually having

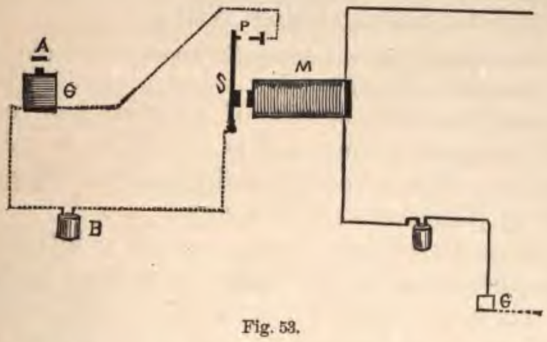

Fig. 53.

the same functions as a key, but being automatically worked by the attraction of the relay.

123. *Why is it that, as just stated, the batteries in a Morse telegraphic circuit are usually placed at the terminal stations?*

It is usual to place half the battery at each end of the line, because, as all lines are more or less liable to defective insulation, such an arrangement tends to give better results on the whole than if the battery power were all at one end. If the battery were so placed, and the insulation at all imperfect, the working current, on account of the leakage, would be much weaker at the distant end than at the battery end.

124. *Is electric telegraphy used for any other than commercial purposes?*

Yes, it is employed for a great variety of different purposes. In contradistinction to commercial and railroad telegraphy—which is properly restricted, in its meaning, to the sending and receiving of messages—systems for other and distinct purposes are here called special systems.

125. *What are the principal special systems used in America?*

The municipal fire-telegraph system, the District or messenger business system, the police telegraph, the Gold and Stock or Exchange printing telegraph, and the automatic fire-signalling system.

126. *Describe in general terms the construction and operation of the municipal fire-telegraph.*

The fire-telegraph system of America has repeatedly proved its great value, and is a well-known American institution. It has been brought to a state of great perfection by the Gamewell Company.

The lines all radiate from a central point, connecting with a number of signal-boxes in various parts of the city. They are uniformly what are termed metallic circuits, the ground forming no part of the circuit; that is, the line, leaving, for example, the copper pole of the battery, after making its circuit of the city returns by another route to the zinc pole of the battery.

In large cities the signals transmitted from the boxes are carried by the wires to a central office, from which the alarm is given to the engine-houses and other necessary points.

The action of the signal-boxes is as follows: When the handle is pulled, a detent is tripped, which permits a circuit-wheel to revolve by a train of clock-work, and so to break the circuit a given number of times, thereby giving the required signal. Portions of the edge of the wheel are made of non-conducting material, and a metallic spring, which forms part of the circuit, presses on the edge of the wheel. When, therefore, the insulated portions pass under the spring the circuit is broken. It will be seen that by altering the relative number and position of the non-conducting portions of the edge of the wheel any required specific arbitrary signal may be given.

The circuit being thus closed and broken by the revolution of the wheel under the spring, the armature of a relay is correspondingly attracted to and withdrawn from its magnet at the central office, and when falling back closes a local circuit and strikes the signal on a bell, at the same time recording it on a register. The operator then repeats the signal to every required point in the system, and the alarm is given. In smaller places, although the operation of the boxes is the same, the alarms when sent in are automatically made known to the proper parties and to the public by automatic repeaters, which set in action bell-strikers at prearranged points. The attendance of an operator is thus rendered unnecessary.

127. *Describe briefly the District system of telegraphy.*

This system has been for several years a great convenience in our cities, and its electrical department is simplicity itself.

The circuits, like those of the fire-telegraph, are metallic, leaving one pole of the battery in the district office, running to a number of boxes placed at the residences and places of business of subscribers, and returning by another route to the other pole of the battery at the office. The boxes are virtually small models of those used for fire service, and consist essentially of a metallic break-wheel and contact-spring, both of which form part of the circuit. When the wheel rotates the circuit is closed and broken, and the signal correspondingly given. Different signals may be sent by the same box by different manipulation. For example, if a box signal was 29, 29 once transmitted may signify that a messenger was wanted; twice, a call for a policeman, and so on. The signals are given by the back stroke of a relay closing a local circuit, embracing a local battery-register and a single-stroke bell. The register records the signal on its strip of paper, and it is simultaneously struck on the bell.

Each subscriber is represented in the office by tickets bearing his number, so that no time is lost in ascertaining from whom the signal is sent. The batteries used in this system are generally of the gravity form, and are not usually very large, as the entire external resistance is not great, the relay being the only electro-magnet at all times in the circuit. If a line breaks, or disconnection from any cause takes place, the break is first localized, and until it can be repaired, a ground connection is attached at the nearest box on each side of the trouble, so as to complete the circuit through the earth. If an accidental connection with the ground should occur, or, as it is technically said, a ground appears on the wires, it is at once tested for by grounding the circuit at the office, and opening or sending signals from various boxes on the circuit. Each box between the office ground and the fault will, when operated, send in its signal, while the boxes beyond the fault will not, they being short-circuited or cut off by being between the fault and the office on the other side, so that neither the relay nor battery is in circuit with them. As soon as the ground localized, it should be removed, because if another ground should appear the effect would be the same as that just indicated—that is, all stations between the two grounds would be cut out.

128. *What is usually the system of police telegraph?*

There is no system especially devoted to police intercommunication, each city possessing such a system using that which, in the eyes of its municipal authorities, appears to be the best.

In New York a dial telegraph, worked by a step-by-step motion, is employed, wherein a pointer or index-hand travels round a dial marked with the letters of the alphabet and the cardinal numerals. Each time the circuit is broken and closed the pointer advances one letter. This system is very popular, on account of the economy of maintenance and the ease with which it is worked.

129. *Describe in a general manner the system of the Exchange printing telegraphs.*

The Exchange printing telegraph is also essentially an American institution, and may now be said to be a necessity among the stock, cotton, and produce brokers of our large cities. The entire business has grown up since 1867. Anything of the nature of a complete history of the business, or any details beyond a general description of its operation, would be out of place here.

The quotations of the market prices of stocks, cotton, and produce are collected from the various exchanges and transmitted, from the office or central operating-room, over a great number of wires to the offices of the subscribers. Information regarding interesting events and general news of the day is also gathered and furnished by special circuits arranged for that purpose. In the place of business of each subscriber is a portable printing instrument which prints the communications in plain Roman type. Many styles of printing instruments have been tried, but they may be all resolved into two classes: first, those operated by the mechanical make and break of the circuit; and, second, those operated by electrical pulsations of alternate positive and negative direction.

An instrument of each character will here be briefly described.

The most generally used instrument of the first class, on account of its simplicity of operation, is what is technically known as the "three-wire stock" instrument, which is, as its name indicates, operated by three distinct wires, one of which influences the alphabetical type-wheel, another the numerical type-wheel, and the third operating the press magnet and printing the quotations. The transmitting device is alternately switched to the alphabet and figure wire; and whenever the type-wheels are brought to the required letter or figure the press-wire is placed automatically in the battery circuit and the impression given.

The wheels are operated by a step-by step propelling escapement, each one on its own arbor, on which is also fixed a star wheel, which is advanced by a lever and pallets attached to the magnet armatures.

The armature-levers are both retracted by strong springs, and the star wheels are so placed that each time the armatures are attracted the type-wheels are advanced one character, and each time they are withdrawn the wheels are advanced another character, so that work is done both by the charge and discharge of the magnets. The press magnet, by special mechanism, causes the strip of paper to advance a certain distance after each impression, so as to be ready for the next one. This instrument is much liked by the patrons, on account of the clear impressions and large type printed by it.

The instruments of the second class mentioned are, if possible, still more simple in construction, though a little more complex in principle, than the machine already described. They require but one line-wire, and the type-wheel prints both letters and figures, being made sufficiently large to contain both. The type-wheel axis is iven by a clock-train operated by a weight or spring, and is controlled by an escapement, A, attached to a polarized armature. This latter vibrates on pivots between the opposite poles of two electro-magnets, T T, placed in the same circuit, facing each other, and both working the same polarized armature. Instead of being vibrated by the alternate opening and closing of the circuit, it is drawn from side to side by rapidly succeeding pulsations of alternate polarity. That is to say, if one pulsation is sent from the positive pole of the battery, the next is sent from the negative pole, and so on; and each pulsation permits the type-wheel to advance one character. A third magnet, P, with a much longer core than the two already mentioned, is also in circuit, and is provided with an armature, whose lever presses up the paper to the type-wheel to print the impression. The rapidly alternating pulsations pass through this magnet, but its armature is not affected until a pause is made, because the alternately opposite pulsations succeed each other so rapidly that the long magnet has not time to become charged sufficiently to attract its armature, which is kept against its back-stop by a stiff spring. When, however, a current of either direction is kept on the line longer than usual, the armature is instantly attracted and the printing performed. The movement for feeding the paper is also performed by the armature-lever of the printing magnet. This instrument prints very rapidly. Both styles of instrument are placed in any required number on a circuit, and any number of circuits may, by relays or other contrivances, be operated by one key-board and operator.

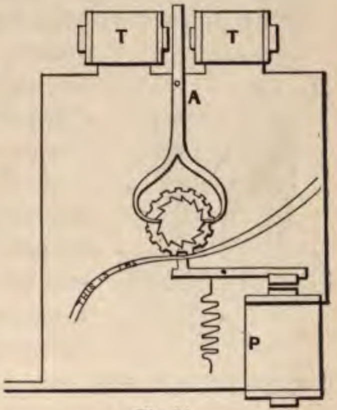

Fig. 54.

Figure 54 is a diagram showing the principle of the latter instrument.

CHAPTER XI.

VOLTAIC CIRCUITS.

130. *What is an electrical circuit?*

The entire path of the electrical current, including the battery itself and the conducting medium which unites its poles.

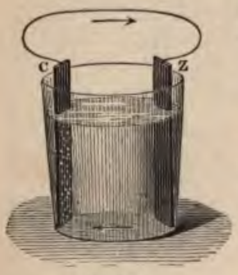

Fig. 55.

If we take a voltaic battery and connect its poles together by a short wire, as in Figure 55, the battery and connecting wire compose the circuit. If we take a battery, connect one pole to the earth and the other pole to a telegraph line-wire, say, one hundred miles in length, with ten relays, and at the end of the one hundred miles connect the line-wire to the earth, the battery, its earth-wire, the line-wire, the ten relays, and the earth itself compose the circuit.

A circuit of which the earth forms a part is called an earth circuit. One in which a return wire is used, or of which the earth forms no part, is called a metallic circuit.

131. *Give a short history of the use of the earth as a part of the circuit.*

The discovery that the earth would serve as a conductor for the galvanic current is usually attributed to Steinheil, who, in 1837 and 1838, was experimenting on a German railroad, with the view, if possible, of using the rails as telegraphic conductors, and thereby dispensing with wires. He found that he could not sufficiently insulate the rails from each other; he then used one insulated wire and rail, which proved to be a perfect success, the rail acting both as a ground and also as a direct conductor. And there is no doubt that to him is due the credit of making and first applying this practical suggestion, which had two great immediate advantages—viz., it halved the number of wires requisite, and on long lines doubled the strength of the working currents.

But it is remarkable that the previous experiments of physicists in completing electrical circuits had not before 1837 been utilized, as it is a fact that as early as 1746 Winckler, of Leipsic, used the river Pleisse to discharge Leyden jars. Le Monnier, of Paris, about the same date, made similar experiments.

It was shown in 1747 by Watson that the earth could always be used as a part of the electric circuit, and his researches were verified both by Franklin and De Luc. These were, however, all researches in frictional or high-tension electricity; but in 1803 Basse, of Hameln, established the fact that the earth could be used as a part of a voltaic circuit. His results were verified by Erman, of Prussia, and Aldini in France, and finally Sömmering and Schilling experimented to the same end and with the same results in 1811.

The apparent neglect of electricians to utilize this valuable fact must have been due to an erroneous idea which they had permitted to take possession of their minds, that the earth could not be employed as a *common* return; in much the same way that the early engineers firmly believed that the locomotive could not run on smooth rails, and that toothed racks and spur-wheels would be necessary. However, when the discovery was actually applied it was, and is still, justly regarded as one of the most important discoveries ever made in the art of electric telegraphy; it is one which has largely contributed to the wonderful extension of telegraphic lines over the world. In long lines it is particularly valuable, as the resistance really offered by the earth and earth-plates is so small in proportion to that of the line that it may be regarded as practically nothing.

The opinions of scientists differ as to the part the earth bears in the circuit, the older theory being that the current leaving the battery flowed along the line, thence to earth, and back through the earth to the other pole of the battery. The newer one, briefly stated, is that the earth is the common reservoir of electricity, into which the current from the battery flows. But whether the earth is or is not, properly speaking, a part of the circuit, the fact remains that it can be used as if it were, which is the most essential point.

132. *On what conditions does the strength of current in a circuit depend?*

The strength of a current in any circuit depends upon the activity of the *electro-motive force* and upon the *resistance* which the electricity has to overcome.

If in a circuit of given electro-motive force and resistance we *increase the electro-motive force*, or if we *decrease the resistance*, we *increase* the current strength. Conversely, if we diminish the electro-motive force or increase the resistance we reduce the current strength.

It must be remembered that the resistance of a circuit includes the resistance of the battery and the conducting wire; also that the current strength is necessarily the same in every part of a circuit. The strength of current is measured or estimated by its power of deflecting the magnetic needle, by its power of electrolysis, by its power of heating a wire of given thickness and material, or by the intensity of magnetism produced by it in an electro-magnet.

133. *How are batteries usually arranged for telegraph lines?*

For telegraph lines the cells of a battery are nearly always arranged in series—that is, connected one after the other, as in Figure 56, the zinc of one being joined to the copper of the next, and so on; because the greatest effective force of any battery is developed when the total external resistance equals the internal resistance of

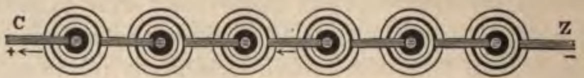

Fig. 56

the battery, and, as it is generally out of the question to obtain such equality on telegraph lines, it follows that the best arrangement of the elements of a battery is that which most nearly approaches it.

Haskins, in his work on the galvanometer, gives the following rule for proportioning a battery to telegraph lines: "Use two cups of Callaud battery for each hundred units of resistance in the circuit. For example, suppose a line 200 miles long, No. 9 wire, 20 ohms to the mile. That is 4,000 ohms. Make the relays equal to it. For instance, 8 relays in circuit, 500 ohms each, which is also 4,000 ohms, making the total external resistance 8,000 ohms. As for each hundred ohms, then, we use two cups of battery, we divide the 8,000 by 50 and find the quotient to be 160, which is the number of cells required."

It is very difficult to lay down any arbitrary rules for the proper proportionment of battery upon a circuit, as so much is dependent upon the size of the line-wire, the insulation, the earth-wires, and even the location of the line. Experience is the best guide in this matter, and the only one to be depended upon.

As previously indicated, it is usual to place half the battery power of a line at each end, so as to reduce the effects of a possible escape.

134. *Are batteries ever arranged differently from the manner described above?*

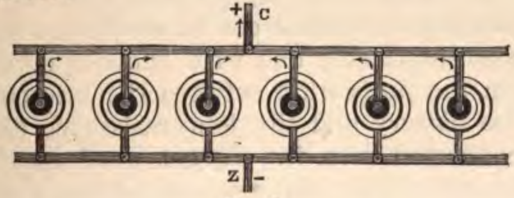

Fig. 57.

Yes, they are sometimes connected side by side—that is, all the zincs are connected together to form one negative pole, and all the coppers together to form one positive pole, as shown in Figure 57.

Their electro-motive force is then no more than the electro-motive force of one cell, while the internal resistance is that of one cell divided by the entire number of cells, being, in fact, equal to one cell whose plates are as large as the combined plates of all the cells we have connected. In this arrangement the cells are connected together to produce the largest amount of current through a circuit of very low resistance.

135. *What rule is given for obtaining the greatest magnetic effect from a given battery?*

When the resistance of the coils of the electro-magnet is equal to the resistance of the rest of the circuit—that is, of the conducting wire and battery—the magnetic force of the given battery is at its height.

136. *Can more than one telegraph circuit be worked from a single battery?*

Yes; when the Grove battery, which has a very low internal resistance and very little tendency to polarize, was in general use in this country, as many as forty and fifty lines have been worked from it; and six or eight lines have been often worked by the carbon battery; but the sulphate-of-copper batteries, which are now universally employed, have too high an internal resistance to allow of more than two or three wires being worked from them. For this reason, when short telegraph lines are operated on closed battery circuits, one battery should never be made to supply more than three lines.

The number of wires that can be worked in this manner, without interfering one with another, depends entirely upon the proportion between the internal resistance of the battery and the joint resistance of all the circuits connected with it. To get good results from this arrangement the battery must have a very low resistance, and the lines worked from it must be approximately equal in resistance and equally well insulated.

Under these circumstances, when several long lines are connected with one common battery the strength of current is about equal on each. The explanation of this is that though, for instance, six lines of equal resistance are being supplied from one battery, and the current supplied by that battery is consequently divided among six conductors, and might, therefore, be supposed to furnish each line with a current of but one-sixth the strength that a conductor worked singly from the battery would have, such is not the case, owing to the fact that the external resistance is diminished and is but one-sixth of the resistance of a single line; or, we may say, the sectional area of the conductor is increased six times, and consequently, we see by Ohm's law, which has already been considered, the strength of current from the battery is increased, so that the loss which arises from the division of the circuit is balanced by the gain resulting from the increased current, due to the reduction of the external resistance. The battery, however, will become exhausted sooner than if it had but one line connected.

The foregoing facts may be familiarly illustrated as follows: A large tank holding water has a pipe of an inch diameter leading out of it, through which the water flows. Suppose now that two more pipes of the same diameter are inserted; a current of water equal to that flowing through the first pipe will flow through each of the other two pipes, because, though the water has to divide itself between three conductors, the conductive capacity is increased, and consequently the volume of water flowing from the tank is increased, the final result being that the water in the tank is more quickly exhausted.

Several very weighty objections are made to the foregoing practice. One is that a battery fault affects all the circuits connected with it; another is that in wet weather, owing to the decreased resistance of the lines, they are apt to interfere with each other; and, in any case, there is no economy in working several lines from one battery, except in the matter of first cost of containing jars and in the space occupied, because the consumption of material is in exact proportion to the work done.

137. *Is there any rule that may be depended upon for proportioning battery power for short lines upon which signalling is effected by breaking and closing the circuit?*

No, there is no absolute rule that can be depended upon in all cases, as the strength of working current depends on several other conditions as much as on the battery. An imperfect ground-wire at the terminal station will often put so much resistance into the line as to destroy the effect of a sufficiently large battery. The safest plan in operating short lines—for example, a line one mile in length with six instruments in circuit—is, after constructing the line, to allow five cells of gravity battery for the mile of line, and add one cell for each instrument in circuit, making eleven cells in all. Then let the total resistance of the electro-magnets be equal to the total resistance of the line and battery.

If the line-wire is No. 12 gauge, and is built of galvanized iron, its resistance will be about 32 ohms, and the internal resistance of the battery, at 2 ohms per cell, is 22 ohms, a total of 54 ohms. The combined resistance of all the electro-magnets should then be also 54 ohms; but to make the figures even we will call the electro-magnets 10 ohms each.

The current will now, if the line is well constructed, enable the magnets to attract their armatures strongly. If it is not strong enough one or two cells may be added; if too strong one or two cells may be taken from the battery.

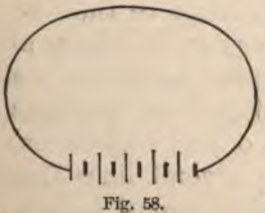
Fig. 58.

138. *To increase the strength of current in a given circuit should extra cells be added in series or should they be added in parallel circuit?*

It is well when placing a battery on a circuit, if the required battery power be unknown, to try first a few cells in series, as in Figure 58; if these do not produce a current of sufficient strength, add more and more cells in series either until the current is strong enough or until the resistance of the battery is double that of the line. If the latter, at this point divide the battery into two equal parts, joining the cells in pairs, as shown in Figure 59. That is, for example, if the total number be sixty, divide it into two complete batteries of thirty cells each, and set these side by side, uniting the zinc poles of both to form one negative pole, and the copper poles of the two batteries to form the positive pole. For this special number of cells this arrangement will give a current of exactly the same strength as when the entire sixty cells were joined in series.

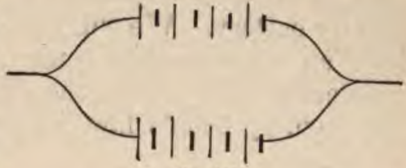
Fig. 59.

Now, to increase the current add in pairs, at each addition adding one cell in series to each row.

To increase the current more and more this method can be readily continued until the whole number of cells employed is such that if all were joined in series their resistance would be six times the external resistance. When this point is reached, to increase the current still more the whole number will have to be divided up and connected in three parallel circuits (see Figure 60), after which additions must be made in threes. The best result in current from a definite number of cells can always be attained by adopting this method.

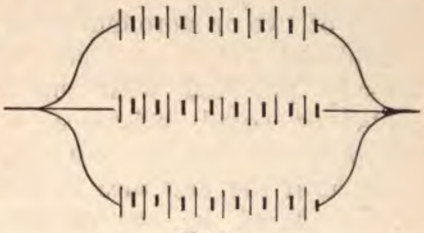
Fig. 60.

139. *Are the results of working more than one line from a single battery more advantageous in short lines than in long ones?*

No, the advantages are even less. This may be clearly illustrated in the following manner: We will first suppose that a line similar to that described in answer 53—that is, a line resistance of 32 ohms and an instrument resistance of 60 ohms, making a total external resistance of 92 ohms—is satisfactorily operated by 11 cells of gravity battery. We will further assume that battery to have an electro-motive force of 11 volts and an internal resistance of 22 ohms; the current on the line will, we see then, by Ohm's law, be .09, or nine-hundredths of an ampère.

We then add two other lines of equal total resistance, and find the amount of current on each line to drop to .07, as, though the current developed from the battery is increased to .21, it has to be divided between three conductors or outlets, which gives a result as stated above, an amount of .07 each. Now, to bring the current on each line up to the normal strength of the first circuit—that is, .09—it will be found necessary to add 9 cells of battery, nearly double the first amount, which shows how little economy there is, even in space occupied, in working batteries on this plan. Every evil result which long lines so worked develop is shown and intensified in short lines.

140. *What is meant by the expression "joint resistance"?*

The term joint resistance means literally the resistances of two or more independent branches of a circuit considered and treated as one. Thus if a battery is already provided with one wire, and a second is added of equal resistance, a second route is thereby provided for the current, and the result is exactly as if the first wire had been taken off altogether and replaced by one of exactly double the weight per foot. If still another wire of the same resistance is added the joint resistance is now but one-third of the original wire, as the conductivity is increased threefold. It follows naturally that the resistance, which is the converse of conductivity, is lessened in the same proportion.

141. *What is the rule for finding the joint resistance of two or more parallel circuits?*

When the resistances of all of the circuits are equal there are three formulas, either of which may be employed:

First. Divide the resistance of one wire by the number of wires. For example, 5 wires each have a resistance of 60 ohms; to obtain the joint resistance of the 5 wires we divide the 60 by 5, and, the quotient being 12, 12 is the joint resistance required.

Second. If there are only two wires divide the product of the respective resistances by their sum. Thus, 2 wires each have the same resistance, 60 ohms; 60 multiplied by 60 equals 3,600; 60 plus 60 is 120; then dividing 3,600 by 120, we have as a quotient 30 ohms, which is the required joint resistance.

Third. Divide the sum of the resistances by the square of the number of the circuits. For example, 6 circuits have a resistance of 60 ohms each. The sum of these resistances is of course 6 times 60, or 360, and the square of the number of circuits—that is, 6 multiplied by 6—is 36. Dividing 360 by 36, we find the result to be 10, which is obviously the joint resistance of the 6 circuits.

When the resistances of the circuits are unequal the following plan must be adopted: If only two wires, divide the product of the resistances by their sum as above.

If the combined resistance of more than two circuits be required, first find the joint resistance of any two of them; then, considering this as one resistance, combine it with a third, and so on. For instance, three wires have respectively the following resistances: 200, 300, and 100 ohms. First take two of them: 200 and 300 multiplied together is equal to 60,000; 200 plus 300 is 500; then 60,000 divided by 500 gives as the joint resistance of the first two wires 120 ohms.

Now, calling that one circuit, we multiply 120 by 100, the resistance of the third wire, finding the product to be 12,000; 120 added to 100 being 220, we now divide the 12,000 by 220, which gives us as a result 54 and a fraction for the joint resistance of the three circuits.

CHAPTER XII.

LINE CONSTRUCTION.

142. *How may the conducting wires of telegraph lines be classified?*

They may be divided into three great classes, viz., *aerial*, *subaqueous*, and *subterranean* wires. The aerial lines may further be subdivided into those supported on poles and those on house-top fixtures, the latter being chiefly employed in large cities.

143. *Under what heads may all materials for the construction of the line be classed—the line here and henceforth to be understood as the conductor, regarded apart from the battery and instruments?*

In the construction of a line of telegraph all the materials employed may be comprised in one or the other of the following three heads: poles or other supports, wires, and insulators.

144. *Give some details concerning the choice and setting of poles.*

The poles used in this country are chiefly of white or red cedar or chestnut. Red cedar is the best, though the most unsightly, but chestnut is the most frequently used, especially in the Atlantic and Middle States.

Poles should in all cases, when cut down, be cleared of all branches, stripped of their bark, shaved smooth, and then stacked for some time in such a manner that the air can freely circulate among them, so that they may be well seasoned. This is too often neglected, and poles are frequently set as soon as they are cut and trimmed. Very little is done for the preservation of poles used on American lines. The European telegraphs are far in advance of ours in this respect. In England the poles, before being set, are treated with solutions of metallic salts, which, being introduced into the pores of the wood by different processes, combine with the sap and prevent decay.

Poles should not be less than twenty-five feet long, nor less than five inches in diameter at the top. Their length must necessarily depend upon the number of wires they are to carry, but on the majority of trunk routes the length varies from twenty-five to forty-five feet. Except when passing through cities or towns they are rarely painted, although such a practice would conduce to their longevity.

They should be set at least five feet deep wherever practicable. The hole they are set in should be kept as narrow as possible, and perpendicular at one side, so that the pole will at least bear against one side of solid earth. When the earth is replaced it should be well tamped down after each few shovels are put in the hole, and moderate-sized stones may be tamped in close to the pole.

All the cross-arms required should be attached before the pole is set, in order to save labor. The ordinary practice is to place them all on one side of the pole. The spaces cut for their reception on the side of the pole are called gains.

In some cases cross-arms are not used, but brackets are employed, which are spiked to the pole, some on one side and some on the other, preferably alternating in this respect. It is a frequent practice also to bore a hole in the end of the pole and insert a pin which will carry an insulator, so that one wire may be strung on the top of the pole. Whenever this is done an iron ring, a little smaller than the top of the pole, should be heated red-hot and slipped over the end of the pole after the pin is driven in, to prevent the smaller end from splitting.

The distance between the poles varies with the nature of the ground and must be left to the judgment of the constructor. But the number of poles to the mile will average about thirty, sometimes increasing to forty, and metimes, on a straight and level road, decreasing to nty. In this connection it may be well to observe that the fewer supports there are, the better the insulation, as each pole forms a branch circuit (of high resistance, it is true, but still a branch circuit) to the earth.

In setting poles round a curve they should be made to lean back against the strain of the curve and should also be firmly guyed.

145. *Give information relating to the attachment of cross-arms.*

Cross-arms should be of white pine, well seasoned. They should also always be planed, bevelled off at the upper corners, and well painted. The length varies with the number of wires to be attached, while the ordinary size of cross-section is four inches by five. In regular telegraph work the cross-arms are longer than in local or city lines. On a trunk line a cross-arm for two wires is about three feet long; for four wires, five feet six inches; and for six wires, seven feet six inches; while the distance between the insulators from centre to centre is generally about twenty-two inches.

No such magnitudes are used on short private telegraph lines, the cross-arms being much shorter in proportion and the insulators placed much nearer together. The cross-arms are fastened to the poles with either a pair of stout spikes or with lag-screws or bolts and nuts. The latter mode is preferable. All cross-arms should be fitted with the pins and insulators before the pole is set up.

146. *Describe the different supports in use for house-top lines, giving proportions of the same.*

These supports, which are technically called *fixtures*, are variously constructed, according to the character of the roof and locality where they are erected. They were, until within the last few years, of very simple construction and comparatively small size; but since the introduction of the telephone exchange systems they have necessarily increased in size, and it is a matter requiring some mechanical skill to maintain the best proportions for strength and capacity.

Two general classes comprise the whole—wall and roof fixtures. These, again, are made single or double, according to the number of wires they are required to support.

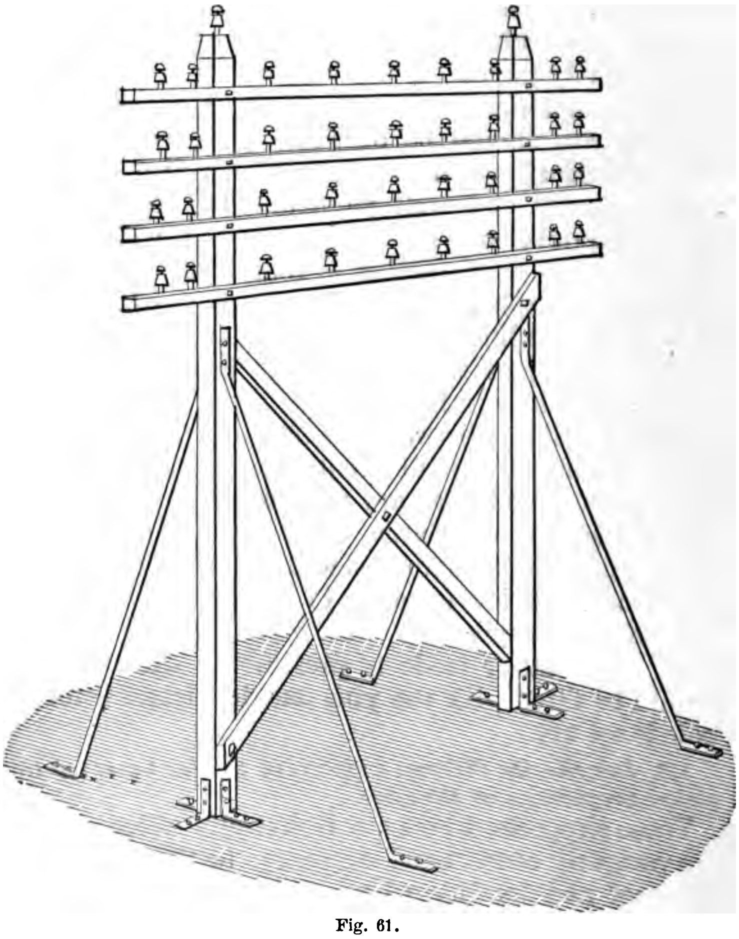

Fig. 61.

A roof fixture is one which is placed on the actual roof of a building.

A wall fixture is spiked to the side-wall of a building or a party-wall.

A double roof fixture for telephone work should be a high, so as to clear all other wires. The upright posts should be at least fifteen feet high and five inches square, the cross-bars fourteen feet long and four by five inches in thickness, and secured to the uprights by lag-screws. The upper cross-bar may be placed one foot from the top of the uprights, and the others eighteen inches apart. If but three are required instead of four, place them two feet apart. The insulators should be at least nine inches from centre to centre. All screws entering the roof should be carefully soldered over to prevent leaks.

In many cases it is preferable, and sometimes even necessary, to use wall fixtures, as they remove all danger of causing leaks in roofs and are equally serviceable where roofs are pitched as when they are flat. The details of this fixture are, in general terms, the same as those of the roof fixture just described. The upright posts have a total length of twenty feet, fifteen feet of which stand above the top of the wall, and the remaining five feet are used for fastening the structure to a piece of plank previously secured to the side of the wall. This plank should be five feet long, about ten inches wide, and two inches thick. It should be spiked to the wall with

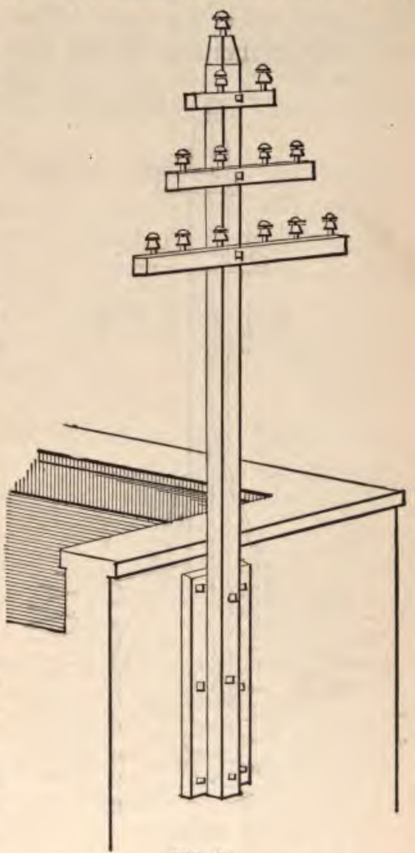

Fig. 62.

seven-inch spikes, and will then form a substantial base for the support of the structure carrying the wires. The upright posts and the cross-bars are the same size, and are arranged in the same manner, as those of the roof fixture.

Where not more than a dozen wires run in one direction they may be supported by single fixtures with one, two, or three cross-arms. The general directions given for double fixtures of the same class may be applied with equal propriety, and either the roof or wall fixture may be used as occasion may demand. The usual length of single roof fixtures is about twelve feet, and the size of stock five by five inches.

Angle-irons are attached by means of lag-screws to the foot of the upright and to the roof. The fixture is firmly braced on three of its sides by rods of one and one-eighth iron, hammered out at the ends, and fastened to the upright and to the roof by lag-screws. The first cross-arm is twelve inches from the top of the upright, and the second and third eighteen inches from centre to centre. The two middle insulators are usually twelve inches apart, each of the others nine inches, and the outside insulators three inches from each end of the cross-arms.

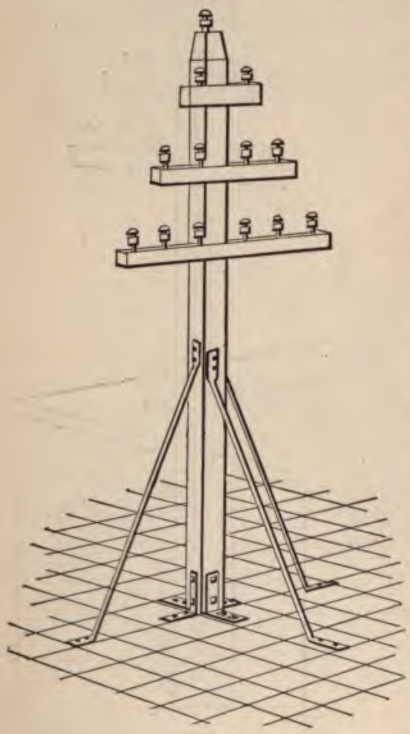

Fig. 63.

The same description applies equally to single wall fixtures, except, of course, the method of attachment, which is similar in every respect to that of the double wall fixture.

The usual insulator employed in house-top work is the glass insulator, either pony or standard size. Hook insulators are undoubtedly preferable in every respect except cost.

All fixtures, cross-arms, and boards should be of white pine and well painted. Spruce should never be used. House-top fixtures should invariably be thoroughly guyed against lateral strain.

If the wires pass in a straight line with the fixture there should be two guys placed, one on each side of the fixture, to hold it against the side-pressure produced by the wind acting on the wires. In case a section on one side of a fixture is longer and heavier than the section on the other side, a guy should be fastened to the fixture to pull against the strain produced by the heaviest section. In case the line makes an angle at the fixture the guys should be disposed so as to pull against the strain. For guy-wire use No. 9 galvanized iron. In arranging all guys the general principle should be remembered that the fixture will simply hold up the line, and the guys must be strong and taut enough to resist all lateral or diagonal strain. Fixtures should not be more than from one hundred and fifty to two hundred feet apart. Sometimes when a single line is to be run light iron attachments are made use of, such as tripods, which, as their name indicates, are three-footed fixtures of round iron carrying an insulator on the apex of the triangle caused by the union at the top of the three legs. Ridge-pole fixtures and chimney-irons are other forms of light attachments which are more or less useful for light work.

147. *What is the use of insulators in telegraph or telephone lines?*

The use of insulators on aerial lines is to prevent the loss of electricity at the points of support. They must, therefore, be made of some substance which is as nearly as possible a non-conductor. It is essential that the electricity should arrive at its destination as little diminished in volume as possible, in order that it may thoroughly and easily perform its office. To this end the conductor must be insulated at every point of support, both from the earth and from any other conducting wire which may be on the same poles.

The fact that some bodies offer very great resistance and that other bodies offer very little resistance to the passage of electricity has rendered the electric telegraph possible. As all substances conduct in a greater or less degree, there is always more or less leakage to earth, and the working value of a telegraph line is the difference between the resistance of the insulators and the resistance of the conductor. It is, therefore, obvious that the better the insulation the better will be the operation of the line. When a wire is carried through damp places, underground, or through water, the insulation has to be continuous and the wire must be covered with india-rubber or gutta-percha.

148. *What are leakage-conductors, and how are they applied to pole lines?*

Leakage is a term applied to the escape of electricity from the wires in very small quantities. It is caused by imperfect insulation, which allows portions of the current to separate from its proper conductor and to divide itself between all the other roads to the ground, in proportion to their respective resistances. These other roads are, first, the pole; and, second, the other wires, which are often of different lengths. So long as the current escapes to the earth no great harm is done, as the only effect is to weaken the signals; but when it leaks into another wire it confuses the signals on the second line. The plan for remedying the trouble, first suggested by the English telegraph engineer Highton 1852, and subsequently patented by Varley in the

United States, is to attach a thick wire to the pole, coiling the earth end in a spiral under the foot of the pole, and continuing the wire till it projects above the top of the pole, thus serving also as a lightning-conductor. Branch wires of a smaller gauge are then fastened to each earth-wire, and extended along the cross-arms to each insulator-pin, to which they are firmly attached. Any current then leaking from a wire will naturally take the quickest way to the earth down the poles *via* the earth-wires. This is most effective in preventing interference between wires when the earth-wire is attached to every pole. The earth-wires, however, do more harm than good when they do not make a good earth connection. A buried plate soldered to the earth-wire makes the best earth.

Within the last few years improvements have been made in leakage-conducting appliances, which have taken the shape of metallic sleeves or sockets, fitted in the holes of the cross-arms in which the insulator-pins are inserted, and united with a continuous wire running from pole to pole and attached to the earth-wire of each. The English insulators, being generally fixed on metallic pins, do not need these metallic sockets.

Considerable attention has of late been given to this point, owing to the rapid increase of telephone lines, which, with their extremely sensitive instruments, render electrical disturbances of any character very evident.

It is, however, still a question as to whether or not it is beneficial to apply these leakage-conductors to telephone lines of more than ten miles in length, on account of the increased electro-static capacity acquired by lines furnished with them. The capacity is greatly increased, since the earth, by means of the ground-wires, is brought quite near to the lines; and this increase in capacity tends to retard the currents made use of in telephony, and causes the spoken words to run together, thus rendering the articulate sounds transmitted undistinguishable.

149. *In choosing insulators what points should be considered?*

In the choice of an insulator the following conditions should be taken into consideration:

The surface between the point where the line-wire touches and the substance of the pin-bracket or pole should be as long and also as narrow as can be attained.

The material of which the insulator is composed should be as perfect a non-conductor as possible.

The insulator should be of such a form that its exterior surface will be thoroughly washed by rain, yet that its interior surface shall *not* be reached by rain.

It should have a surface which repels moisture.

It should be strong enough to resist any strain likely to be brought to bear on it.

It should be economical in first cost.

There is, however, no insulator that combines all these virtues, and the best way is to choose that which comprises the majority of them.

Hard rubber is one of the best insulators, but soon loses its surface and becomes rough and spongy when exposed to the weather. Glass, regarded simply as a non-conductor, is one of the best, but is objectionable from the fact that its surface has a great affinity for moisture and will be covered with a moist film in nearly every state of the weather. It is, however, both cheap and convenient; and these considerations, in this country, so override all others that it is almost universally used.

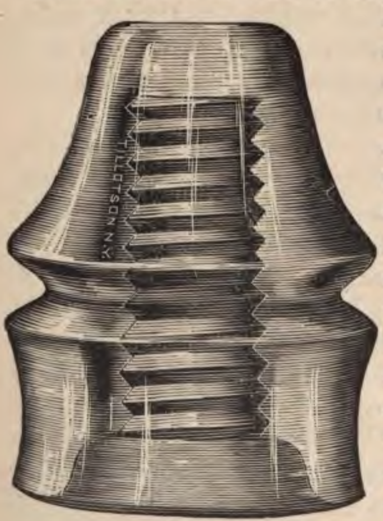
TILLOTSON N.Y.

Fig. 64.

150. *Describe some of the best or most generally employed insulators.*

The unprotected glass insulator, which is in almost universal use in this country, naturally takes precedence with an American writer. It is generally made in the form represented by Figure 64.

Though perhaps not so perfect an insulator in many respects as some others, its low price, more than fair insulating properties, and convenience of attachment enable it to maintain its place in the front rank.

As now made it has a screw-thread on the inside, by which it is secured to its supporting bracket or pin. The under side below the screw swells out, and the concavity thus formed keeps always a certain amount of dry surface and prevents an escape in wet weather. The line-wire is passed alongside the groove surrounding the insulator near the top, and is fastened with a tie-wire, which passes around the insulator, while both of its ends are twisted around the line-wire.

The glass insulator with a wooden covering is used to some little extent in the United States. It is shown in Figure 65, and has no particular features except those indicated by its name. It is to be objected to chiefly because when an insulator becomes defective it is a very difficult matter to discover the defect; and, moreover, it has been ascertained that when such insulators are used the percentage of leakage is comparatively high.

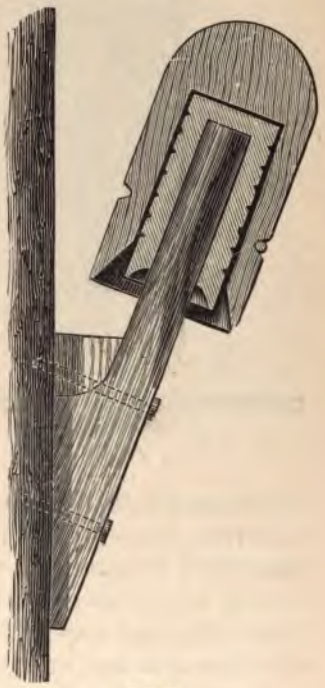
Fig. 65.

Next comes the brown earthenware insulator, which is in general use in England. It is composed of two separate cups, the smaller of which is fitted into the larger, and is fastened by a cement consisting of equal parts of fine sand, cement, and plaster of Paris. The iron bolt is galvanized, and is fixed in the inner cup by another cement, which is composed of five parts of clean sand, three parts ashes from a locomotive fire-box, and two parts pine resin. A groove is formed on the upper part of the insulator, and in this the line-wire is bound, in a manner similar to the glass insulator.

It may be well here to state that sulphur is not a good insulator cement, as it splits the insulator, apparently by expansion.

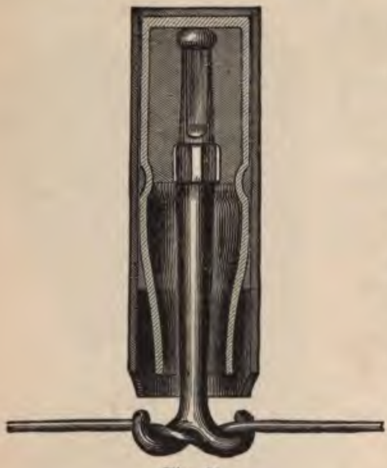

Fig. 66.

The Brooks insulator, Figure 66, is in many respects an excellent one, and gives very satisfactory results, especially in localities where insects are not too numerous. It consists of an iron wire-holding hook cemented into a blown-glass bottle, which is inverted, so that the hook hangs down. The bottle is cemented into a cast-iron shell, which is either provided with an arm that screws into the pole, or, if to be placed on a cross-arm, is arranged with a projecting piece, whereby it may be inserted into a hole on the under side of the cross-arm, and locked by a pin which is passed through the cross-arm and engages the projecting piece.

The remarkable insulating properties of this combination are due to two causes: first, the liberal use of paraffine, with which the cement is saturated; and, second, the great power of repelling moisture possessed by blown glass.

The last insulator which it is necessary to mention is

The last insulator which it is necessary to mention is the "rubber hook." It is simply an iron hook whose shank is firmly fixed into a mass of hard rubber. A thread is cut on the rubber for screwing into cross-arms. On account of its great mechanical strength and convenient form it is much used on short city lines. Its high price and the deterioration of its insulating qualities after a few years have prevented its extended use on long lines.

151. *What is usually the material of the conductor in aerial lines?*

The materials of which aerial conductors are made are iron, copper, steel, and several kinds of bronze.

Iron is largely used in telegraphy and short-line telephony, because it is cheap, durable, has a not unreasonable resistance, and great tensile strength, and it should always be zinc coated.

The best iron wire is made of charcoal iron, which, after being drawn, has a high degree of toughness.

Steel wires are used to some extent for very short telegraph and telephone over-house lines, where a high degree of conductivity is not essential; their advantages are that they have considerable strength, that they permit of the employment of much lighter fixtures, and that householders are much more willing to allow a light wire than a heavy one to be attached to their houses.

Copper wire (hard drawn) is now also much used for long telegraph and telephone lines, and it is especially well adapted for the latter by reason of its low resistance and low self-induction. It can be made of considerable strength, and its employment in long-distance telephone lines is universal.

152. *What sizes and brands of wire are chiefly employed?*

For telegraph lines of medium length—for example, 100 to 300 miles—wire of No. 8 or 9 Birmingham gauge is generally employed. The size of No. 8 is .165 of an inch, its weight per mile about 385 pounds, and its resistance nearly 13 ohms per mile; while 409 feet measure 1 ohm in resistance. The size of No. 9 is about .148 of an inch, its weight per mile about 324 pounds, its resistance per mile 16.1 ohms, and 328 feet of it give a resistance of 1 ohm.

For very long lines—for example, from New York to St. Louis or Chicago—Nos. 4 and 6 are used. The size of No. 4 is .238 of an inch, and of No. 6 .203 of an inch. The weight of No. 4 is about 887 pounds to the mile, and of No. 6 about 570 pounds. The resistance per mile of No. 4 is about 5½ ohms, that of No. 6 about 8½ ohms. For lines but a few miles long—in short, for any line less than 25 miles in length—Nos. 10 and 11 will answer very well, while for very short city lines, employed either as telegraph or telephone wires, Nos. 12 and 14 are as large as necessary. Their sizes and resistances vary as follows: The size of No. 10 in mils, or thousandths of an inch, is 134, No. 11 is 120, No. 12 is 109, and No. 14 is 83. Their respective weights per mile are 249, 200, 165, and 95 pounds, and their respective resistances 19½, 24½, 29½, and 51 ohms per mile. These figures are approximately correct. They are necessarily modified, however, in each individual case by the different gauges in use by different manufacturers.

The best brand of wire for telegraphic purposes is undoubtedly charcoal wire. It is now more used in France than anywhere else. "Extra-Best-Best," known commercially by the cabalistic symbols E. B. B., is generally used in this country, and is a first-class quality of wire.

The above refers altogether to iron wire. Copper wire of smaller size can be used with advantage. The sizes of copper wire used in telephony are respectively No. 12 and No. 14, and in rare cases No. 11, of the Brown and Sharpe or American gauge.

The resistances of these sizes are as follows: No. 11, 6.656 ohms; No. 12, 8.394 ohms; and No. 14, 13.680 ohms per mile. By using copper wire of say No. 12 size for telegraphy, the line can be worked as economically as regards battery-power as though an iron wire of about six times the cross-section were employed.

153. *Have any steps been taken toward the general introduction of an improved wire-gauge? If so, with what result?*

In view of the fact that the Birmingham wire-gauge, which nominally had been a standard, varied with every manufacturer, a new gauge was devised in England, adopted by the English Board of Trade and legalized March 1, 1884. A copy of this gauge will be found in the appendix.

This gauge, though formally endorsed by the National Telephone Exchange Association, September 8, 1885, has been but little used in the United States; and consumers generally, in ordering wire, usually specify the diameter in thousandths of an inch.

154. *Should a large or small size gauge of wire be preferred for long lines?*

The longer a line the larger should be the gauge of wire used, as illustrated by the fact that on the short private lines so well known in cities Nos. 11, 12, and 14 are generally used; on telegraphs of ordinary length between commercial points Nos. 8 and 9 are commonly employed, and for the longest telegraph lines—such as those between New York and Chicago, and New York and St. Louis—Nos. 6 and 4 either are or should be used. The largest size used in England is No. 4, which is nearly a quarter of an inch in diameter.

155. *What are the reasons for using large wires for long lines?*

In the first place, the smaller the wire the more care is needed in insulation; the smaller a line-wire is the less is its conducting power, and, necessarily, the greater is its resistance. In a line the current from a battery has a choice of routes, so to speak—either to traverse the line-wire, thereby arriving at the distant point, or to leak to ground over each insulator and down each pole. A certain amount of leakage does take place at every pole, and therefore the current does actually divide between the two routes in direct proportion to their respective conductivities. Although the amount of electricity which leaks off at one pole is inconsiderable, yet when we remember that there is an average of thirty poles to the mile, and possibly a great number of miles to the line, we see that the total amount of leakage is by no means inconsiderable. We must further consider that the resistance of a line-wire increases in direct proportion to its length; that is, if a wire 100 miles long has a resistance of 1,000 ohms, when extended to 200 miles long the resistance will be 2,000 ohms, provided the wire is kept the same size. The result is that every line, as it is made longer, decreases the resistance of its insulation by adding many more poles, at each of which there will be some leakage, while it also has the resistance of its proper conductor increased, because each mile of wire adds a mile of resistance. It is obvious, then, that to maintain the conductivity of the line at its proper standard we must increase its size and thereby keep its resistance down. We shall, by so doing, economize battery power, because reducing the line resistance practically shortens the circuit. By using smaller batteries we gain incidentally another advantage—namely, the decreased tension of the current, and consequently its decreased ability to escape, or the greater ease with which it may be insulated. Another point in favor of large wires is that they are much more durable in proportion than small ones.

156. *What sizes and qualities of wire are suitable for telephone lines?*

Any kind of wire that is suitable for telegraph lines is, in the abstract, equally suitable for telephone lines, both as a matter of economy in first cost and for ease in manipulation; it has, however, been found expedient ordinarily not to use a larger wire than No. 12, galvanized iron. Where iron is still employed for long lines, such as those between cities, Nos. 8 and 9 are generally used.

For short lines in positions where they are alone, and are not switched to others for through communication, a much smaller wire of steel can often profitably be employed, for the following reasons: A small steel wire is as strong as a much larger iron wire. It is, therefore, very easy to handle while it is being strung, and this is quite a consideration. It is also a comparatively easy matter to obtain permission to erect a fixture on a roof where very light wires are employed, and, moreover, by using small wires induction is much diminished. On the other hand, the resistance of the conductor is greatly increased, both because that conductor is steel and because a small wire is used. Insulation is thereby rendered proportionately difficult. These considerations cannot, however, outweigh the previous ones, because on such short lines as those we are speaking of—for example, from half a mile to a mile long—the resistance, at the greatest, is not so much as to render the line at all difficult of insulation; and, in the second place, no sensible difference is perceived in using a telephone, even where the resistance is considerably increased. Furthermore, so far as signalling is concerned, the recent practice is decidedly to use magneto-electricity for signalling, and such currents can never have any difficulty in doing a reasonable amount of work or in ringing a bell loudly over more miles of steel wire than can be required within the limits of any American city.

As already stated, copper wire is rapidly coming into use, and is admirably adapted for either long or short telephone lines. Light phosphor bronze wires are used considerably on the Continent of Europe, and for some purposes in the United States, especially for long spans where a light wire is useful. Its electrical resistance is higher than might have been expected.

157. *What is meant by the term galvanized wire?*

When we speak of galvanized wire we mean nothing more nor less than zinc-coated wire; and the term galvanization is entirely misapplied when so used.

Telegraph wire is nearly always galvanized, in order to preserve it from destruction by the oxygen of the air. If not so protected the wire is eaten away by rust very rapidly. When properly applied the zinc coating is very effectual in preserving the iron wire from oxidation, and this it accomplishes in two ways: first, by acting as a mechanical covering and protection for the iron wire; second, by its electrical qualities being more electro positive than iron—that is, having a greater affinity for oxygen than iron. When associated with it the iron is protected from the action of the oxygen at the expense of the zinc. But when the zinc is attacked by the atmospheric oxygen it is converted into oxide of zinc. This, not being soluble in water, remains on the wire, and so protects it from corrosion. In the vicinity of places where much coal is burned, however, the air is heavily charged with sulphurous acid gas; this transforms the oxide of zinc into sulphate of zinc, which, being readily soluble in water, is washed away, leaving the iron unprotected. This is the reason that iron wire in the vicinity of large manufacturing towns so soon rusts away. If it can be done it is a very good plan to paint wires in such localities. Galvanizing is now performed in a much more effective and efficient manner than formerly, and, as the wire is by the same process annealed, its mechanical qualities are left comparatively unimpaired; still, the iron is by the process made a little harder.

158. *What mechanical tests are usually applied to telegraph-wire?*

Only two tests are generally applied in America to line-wire—namely, for *ductility* and *tensile strength.*

The first is made by twisting short pieces of wire between two vises; the second by the direct application of weight. Two other tests are desirable and easily applied. As the value of these tests depends mainly upon the way they are applied, we will describe the four methods somewhat in detail.

The *first* mechanical test which should be applied is so simple as to be within the means of every one, and is for *pliability*. The wire should be capable of being bent four times to a right angle with itself, while held in a vise, without injury. The *second* test is to the same end and is equally easy of application. The wire should be capable of being wound around itself a certain number of times without breaking. The *third* test is universally employed, both by the Western Union Company in this country and by the telegraph departments in the principal European countries, and, as previously indicated, if well performed this test is valuable; if performed in a slovenly manner it counts for nothing. It is to subject a sample of the given wire to twisting, and also is a test for ductility. The piece of wire is placed between two vises six inches apart, and twisted; the greater the number of twists that it will bear without splitting or breaking, the better is the ductility of the wire. The twists are reckoned by the spiral formed by a line drawn longitudinally along the wire with ink before the test. The number of the twists in wire of the same quality depends upon the size of the wire. For No. 9 it should not fall below fifteen twists in the six inches, or for No. 12 below seventeen. To give the test a proper degree of value the vise-jaws should not have sharp edges, or they will cut the wire and cause it to break close to the vise. The number of twists that any wire should bear varies (roughly) inversely with its diameter. That is, the number of twists that a wire will stand increases in the same proportion as its diameter decreases. The *fourth* test is for tensile strength.

The wire is required to carry a certain weight or resist a certain strain without breaking. This test is universal in its application. The requirement of the Western Union Company is that the wire must be capable of elongating fifteen per cent. without breaking, and that it must not break under a less strain than two and a half times its own weight per mile. This test is sometimes made with a hydraulic machine, but oftener with a scale and weights. The last method is much to be preferred, because in the former the additional strain is apt to be too rapidly applied, and the wire, not having time to stretch to the individual strain, will show a greater strength than it has. Using a scale or lever, the weights should be slowly applied and the wire given time to stretch. If the wire to be tested is to be suspended from a hook, it will not do to fasten it with a twist splice, as such a splice will not stand the strain. The wire should be closely wound around the hook and the end brought down parallel to the wire, the two being then closely wrapped with binding-wire.

159. *What amount of stretching should good iron wire bear without breaking?*

In different countries different standards are given. For example, on the government telegraphs in England line-wire is required to be able to elongate eighteen per cent. before breaking. The Western Union Telegraph Company specifies that line-wire must be capable of a fifteen per cent. elongation. It is safe to say that any wire for telegraph purposes should at least be capable of stretching to the latter percentage. The breaking strain should be not less than two and a half times the weight of the wire per mile; that is, if a mile of wire weighs two hundred pounds, and a piece of it is undergoing a test for strength by suspending weights from it, the wire should not break until the amount of weight reaches five hundred pounds.

160. *What electrical tests should telegraph-wire be required to pass?*

Electrical tests are more especially necessary when the wire is to be used on long circuits. The electrical properties of wire have been found to vary considerably, and frequently the strongest and most ductile wire, or that which tested mechanically is the best, when electrically tested is found to be much inferior for telegraphic purposes to other wires by no means so good otherwise.

The only test much used, however, is for resistance. The ordinary practice in this country is, when ordering wire, to stipulate that the resistance of the wire in ohms per mile, at 60 degrees Fahr., must not exceed the quotient of the number 5,500 divided by the weight of the wire in pounds per mile. For example, if we order No. 12 wire and assume the weight to be 165 pounds per mile, to find out what resistance we require we divide 5,500 by 165. Finding the quotient to be $33\frac{1}{3}$, we order No. 12 wire, 165 pounds to the mile and with a resistance not higher than $33\frac{1}{3}$ ohms per mile. Similarly, a wire No. 9—which we will call 325 pounds per mile—should have a resistance not greater than 5,500 divided by 325, viz., $16\frac{12}{13}$ ohms.

161. *Does the resistance of wire vary with the temperature?*

Yes; the resistance of all wires increases as the temperature rises, and the resistance of nearly all metals increases at the same rate, iron and thallium, according to Dr. Matthiesen, being the only exceptions. From the tables given by Latimer Clark we learn that the resistance of iron wire increases about thirty-five hundredths (.35) per cent. for each degree Fahrenheit, and that the resistance of copper increases, as the temperature rises, twenty-one hundredths (.21) per cent. for each degree.

The rate of increase is not reckoned all through on the original resistance, but is computed in the same manner as compound interest on a sum of money. For example, if we have a wire which measures 100 ohms at 60 degrees Fahrenheit, and the resistance be increased a certain amount by a rise of one degree in temperature, it will be increased by the next degree of rise at the same rate per cent., calculated on the original resistance, plus the amount increased by the first degree of rise.

162. *The diameter of any iron wire being given, how may the weight per mile be ascertained?*

If we know the diameter of any size of iron wire, in mils, or thousandths of an inch, we may find the weight per mile by dividing the square of the diameter in mils by the constant number 72.15.

For example, we have a No. 12 iron wire, and wish to find its weight per mile. It is, we will suppose, 109 mils in diameter. The square of 109, or 109 multiplied by itself, is 11,881. Dividing this number, 11,881, by 72.15, we find the quotient to be about 164⅔ pounds, which is the weight per mile. The weight of copper wire is found in the same way, substituting 63.13 for the number 72.15.

163. *What is meant by the killing of wire?*

It is a term much used in England, where it is applied to the process of stretching the line-wire in a cold state before stringing it. The average amount of length gained by thus stretching should be two inches in every hundred. The purpose of the operation is not to increase the length of the wire, but it is that weak places, caused by bad joints, bad welds, or other imperfections, may be detected and the wire broken before it is strung; avoiding thus the annoyance of subsequent breakage and the trouble and delay attending the necessary repairs. Not only are these weak places detected by this process, but the small bends and wrinkles existing in ordinary wire are straightened out, the wire is rendered less springy, more manageable, and has much less tendency to cross with other wires when acted on by the wind. The method of killing is by Mr. Culley described in the following words: "The wire should be laid out at the feet of the poles, drawn as tight as possible by ropes and blocks, and then pulled at the centre of its length, at a right angle, till it stretches. It will be found to have lost its spring and to lie on the ground as if it had been *killed.*"

164. *What is to be understood when the dip of a line-wire is spoken of?*

The *dip* of any telegraph line-wire is the sag between the poles; that is, when a wire is strung it is never pulled up perfectly tight between the poles, because if it were so strung it would break very easily from any cause. Consequently, between the poles the wire dips, or sags, down in a wide curve, which is deepest at the middle of the distance from pole to pole.

165. *How is the tension, or degree of tightness, with which wires are strung regulated? And is there any dip which is regarded as a standard?*

In America there has been very little regular practice of this kind, and the only rule has been for every line foreman to do that which was right in his own eyes; and, in view of such a fact, the small amount of trouble that our lines give on the average is astonishing. It is, however, an obvious fact that line-wires must be strung sufficiently tight to prevent crosses, and sufficiently slack to avoid breakage from slight causes or from any ordinary change in the temperature of the air. It has been ascertained by the British telegraph engineers that this happy medium is attained when the dip, with a temperature of 60 degrees Fahrenheit, is twenty-four inches in a span of one hundred yards. This dip may, then, be approximately taken as a standard.

166. *When the distance between the poles varies, by what rule can the proper dip be ascertained, in order to maintain the wire at the same distance from the ground at the lowest point of each span?*

The dip of any span of wire—that is, the actual perpendicular distance from the highest point of the span to the lowest—varies, not in proportion to the distance between one pole and the next, but with the square of that distance.

It adds much to the symmetrical appearance of a line, to say nothing of its superior operation, when the tension is made uniform from pole to pole all through the line ; and this may be secured by remembering the statement given in the previous answer. We have already seen that 24 inches in a hundred yards may be taken as a standard, and we now see from the foregoing observations that the formula for finding any required dip must be: That the square of 100 bears the same proportion to the square of the length of the span under consideration as 24 does to the dip required in inches. If, then, we wish from this to ascertain the height of the supports on the poles, so as to keep the dip between the spans a uniform distance from the ground, all that we have to do is to add the amount of dip, which we have ascertained, to the distance which we have decided upon as the distance from the lowest point of each span to the ground, which gives as a result the height of pole support required.

To reduce these rules to practice we illustrate by the following examples: We have a line, and the majority of the poles are 100 yards apart. Some spans, however, are, from circumstances over which we have no control, 150 yards long, and one 200 yards long. It is required to find the proper dip that should be allowed in the longer spans, so as to keep the wire at an even distance of 25 feet from the ground at the lowest point of each span.

We do this as follows, keeping in mind the above formula: Finding that the square of 100 is 10,000, and that the square of 150 is 22,500, by simple proportion it is readily ascertained that 10,000 is to 22,500 as 24 is to 54 inches, or 4 feet and 6 inches. This, therefore, is the requisite dip for a span 150 yards long. Now, to find the height at which this span should be supported at the poles, all we need do is to add the 25 feet that we have stipulated for as the lowest point of the dip to the dip itself—25 feet added to 4 feet 6 inches gives a height of 29 feet 6 inches, which must be the height of the insulator from the ground.

We now consider the span of 200 feet long, and proceed as before. The square of 100, that is, 10,000, bears the same proportion to the square of 200, or 40,000, as 24 bears to 96 inches, or 8 feet. Eight feet, therefore, must be allowed in this case, and the supports made 33 feet from the ground. In these remarks it is not to be understood that an arbitrary standard of 24 inches dip in 100 yards is insisted upon; but having already decided upon a standard dip, it is desired to show how to maintain that dip uniform.

167. *What are the different styles of line-wire joint or splice in general use? How are they made, and which is the best?*

The joint in general use in America is the common twist-joint. The Britannia joint is always used in England, and a peculiar joint, in which both wire ends are twisted together round each other, is used in France. A joint which should never, under any circumstances, be used anywhere is the so-called bell-hanger's joint.

In describing how they are made we will take the last first. The bell-hanger's joint is made by simply hooking the two wires together and bending back the ends. No telegraph man using this, even as a makeshift, can hope for success in his business.

The French joint is made by laying the ends to be spliced together for about six inches; a particular form of hand-vise is then screwed to each end, and the two vises turned in opposite directions until the ends are completely wound on.

The Britannia joint is much praised by English writers, and, from its construction, must necessarily be an excellent joint. It is made by bending the extreme ends of the wires short up with the pliers, placing the wires side by side, and then binding No. 16 wire tightly around them. The whole is then well soldered. Of course, before making the joint the ends are made perfectly clean and bright.

The American twist-joint is shown in Figure 67, and, though not a masterpiece of electrical engineering, will always maintain its popularity on account of the ease and rapidity with which it is made. In making this joint, after cleaning the ends until a bright metallic surface is obtained, the ends are put together and each one in turn twisted round the other, making the successive turns as close to each other and as nearly at right angles to the line as possible. Make four or five turns, then cut off the ends close to the splice. In the construction of a line nothing is more essential to its success than the perfection of its joints. Nothing like the attention that the subject deserves has been given to it in this country.

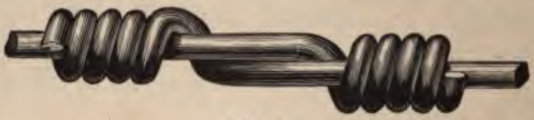

Fig. 67.

Every joint should be soldered, whether between iron and iron or between iron and copper. A single defective joint will often exceed fifty miles of line in resistance. A case once fell within the writer's own experience where a short local line, whose normal resistance was less than 250 ohms, rose to 2,500 ohms. This resistance was located and found to be all in one point, between an iron and a copper wire; the joint was unsoldered.

When a chloride-of-zinc solution is used for soldering copper and iron, before leaving the joint it should be washed off. It is better, however, in such a case to use resin as a flux.

168. *What is the cause of the humming noise often heard where wires are attached, and how may it be prevented?*

This noise, which is frequently so loud as to be very annoying, especially to the inmates of houses over which the wires are run, is caused by the vibration of the wires under the influence of the wind, in the manner of an Æolian harp. It may be prevented in the following way: Two pieces of stout india-rubber tube, like that used for covering the rollers of wringing-machines, are cut about two inches long, and one is fastened at each end of a piece of line-wire, four or five feet long, by passing the wire through it and twisting it back on itself. This piece of wire is then fastened at its centre to the insulator, as usual, by a tie-wire. The line-wire is then cut and an end fastened to each of the sections of hose by passing it round the outside of the piece of hose, and twisting. To preserve the continuity of the line a small iron or copper wire is then connected and soldered to the two ends of the line beyond the rubber. The insertion of a piece of small-sized metallic chain in the line, provided with a continuity-preserving small wire, is also sometimes successfully adopted. Other remedies, all tending to the same end, are occasionally employed, the main object in each case being to prevent the vibration by interposing a damper.

169. *How should an aerial line be led into a way-station?*

There are several methods. In an ordinary telegraph line the usual way is to plant a pole directly in front of the window into which the wires are to enter, and run the wires from each side to a separate bracket and insulator, from thence looping them in. For short lines, such as those in cities, which are frequently house-top wires, a mode often adopted is to run the wire to a batten or counter-brace overhanging the eave, fasten it there to a hook insulator, and then drop it down to a block of wood, bevelled on one corner, which is spiked to the wall close to the window where an entrance is to be made. Another way is to divide the line by the insertion of a non-conducting substance, such as a block or ring of glass or rubber, and to attach the conducting wire to the main wire on both sides of the insulator. To conduct the wires from the point where the line-wire terminates there are also various plans in use. If the line is not a new one, but is already in use, a cut-out must invariably be applied across the new loop until the job is complete; that is, the two wires of the loop must be connected by a short wire. The ordinary line-wire may be led into an office if a hard-rubber tube is inserted into the entering hole. The tube is fastened in the hole with its outer end inclined down, so that no moisture can enter, and the wires then passed through and fastened on the inside. Another way often used is to terminate the line-wire at the hook, or insulator, just outside the entering hole, by twisting it around the hook and then wrapping it back on itself. About four inches of the line-wire outside of the twist-joint are then brightened, and a piece of kerite or rubber-covered wire stripped at the end for about eight inches; the bared wire is also made very bright, and is then, commencing at the lowest point, carefully and tightly wound around the brightened part of the line-wire. The covered wire is finally led through the hole in the window or wall and secured in any desirable way on the inside.*

Sometimes, when many wires enter a building, a cupola is built for their reception. On entering they are led to binding-posts, from whence they are directed to any desirable point.

This work of leading in wires is very important, as, if unskilfully or negligently performed, escapes are very likely to occur in or about the window-casing.

170. *How should an aerial line be led into a terminal office?*

Where many lines—either pole or house-top—are run, a cupola is frequently used, into which the wires are led, as indicated above.

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* It is well to know that gutta-percha-covered wire is not suitable for this kind of work unless well covered with tape soaked in preserving mixture consisting of wood-tar, gas-tar, and slacked lime, because the gutta-percha is soon oxidized and rendered useless by the action of the air.

Sometimes also they are terminated at a pole by winding them back on themselves after being bound to the insulator. A plan often adopted in cities is to range a cross-bar outside the window where the wires are to enter, and screw a sufficient number of hook insulators into it, upon which the wires coming down from the fixture or pole are terminated by winding back.

171. *Are aerial wires ever carried in cables?*

Yes; it is often desirable to run a number of wires over the same route for a short distance where the available space is circumscribed. In such cases cables are very useful, and are employed by several of the city telephone companies of America.

They will be still more universally employed in the future, as the number of wires is, owing to the rapid extension of telephonic communication, daily increasing.

The idea of suspending light cables, containing a number of wires, in the air and over the house-tops, is due to Sir Charles Wheatstone, who suggested it some eighteen years ago. Cables containing as many as fifty wires have been in use in London for a long time, and are suspended by frequent hooks from No. 8 wires. Some of the principal telephone exchanges of the United States have extensively adopted the use of the aerial cable and find it to be a great convenience. San Francisco and Pittsburgh were among the first cities to use such cables, but many are now to be found in Boston, New York, Cincinnati, and other places.

172. *Describe the construction of the cables most frequently used in telephone work.*

A recent construction of telephone cable provides that whether intended for metallic circuit work or not, the enclosed conductors shall be laid up in twisted pairs. By following this plan, metallic circuits can whenever it becomes desirable be readily substituted for single-wire circuits. A cable lately recommended by telephonic authorities is described in the following specification:

1. *Conductors.*

Each conductor shall be .03589 inch in diameter (19 B and S gauge) and have a conductivity of 98 p. c. of that of pure copper.

Each conductor shall have a resistance not exceeding 46 ohms for each mile of cable, after the cable is laid and connected to terminals.

2. *Thickness of Insulation.*

Each conductor shall be so insulated that 52 pairs of twisted conductors shall form a core having a diameter not exceeding 1⅝ inches, and such core shall be placed in a pipe having an internal diameter of not less than 1¾ inches.

When cables containing a number of conductors other than 52 pairs are required, this same proportionate space per conductor and the same proportionate inside diameter of pipe must be allowed as a minimum.

3. *Twisted Pairs.*

The conductors shall be so twisted in pairs that there shall be no inductive disturbance between the circuits.

4. *Outside Covering.*

The core shall be enclosed in a pipe made of an alloy of 97% lead and 3% tin. The pipe shall be free from holes or other defects, and of uniform thickness and composition.

5. *Electro-static Capacity.*

The average electro-static capacity shall not exceed .085 of a microfarad per mile, each wire being measured against all the others, and the sheath grounded; the electro-static capacity of any wire so measured shall not exceed .090 of a microfarad per mile.

In suspending overhead cables, lightning-arresters should carefully be applied at both ends; and a fuse at the outer end.

173. *Are covered wires ever used on house-top lines?*

Yes; in cities, particularly between the centres of business, it becomes almost a necessity to employ covered wires, on account of the great number of lines which cross and recross each other in every direction. In New York, for example, the Gold and Stock Telegraph Company uses rubber-covered or kerite line-wire; and many troubles of a minor character to which its lines would otherwise be peculiarly liable, by reason of the high tension currents employed on printing circuits, are thus prevented or rendered innocuous.

CHAPTER XIII.

SUBTERRANEAN AND SUBMARINE CONDUCTORS.

174. *What metal is usually preferred for the conducting-wires in underground work, and what materials are chiefly used in insulation?*

Copper has always been used as an underground telegraph wire, to the exclusion of all other materials; the most usual size is No. 18, covered with gutta-percha till it reaches the size of No. 7, B. W. G. In England these wires are wrapped with strong cotton tape saturated with Stockholm tar, and drawn into buried leaden or iron tubes. At suitable distances apart are laid testing and drawing-in boxes, into which the ends of the tubes project; and by means of these boxes or chambers access may at any time be had to the wires, and all necessary repairs or changes made. Insulating materials of almost every description have been tried. Gutta-percha and india-rubber are, however, the principal materials used at the present day. The latter has, upon the whole, given the best results when it has been protected from air and insects. Kerite * has given satisfaction, and is much used in the United States.

175. *When was the first underground telegraph laid, and by whom?*

The first underground telegraph line ever laid was that of Francis Ronalds, an English gentleman, in the year 1816. He invented a telegraph to be operated by synchronously moving dials in conjunction with static electricity, and worked it over a wire five hundred and twenty-five feet long, which was laid in a trench dug in the earth for that purpose. The wire was placed in tubes of thick glass, and these were laid in troughs of dry wood, two inches square, filled in with pitch. Ronalds was a strenuous advocate, at that early day, of underground telegraphs.

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* Kerite is a compound of oxidized vegetable oils with tar or asphaltum, which is applied to the wire and afterwards vulcanized by sulphur and heat. Patented by Austin G. Day, October 9, 1866.

176. *Are telegraph wires at present laid underground to any great extent?*

Underground lines are extensively employed in some of the cities of England, and, as constructed, appear to work well. Several longer lines are also in use, notably one between Liverpool and Manchester, a distance of about thirty-six miles. More than one hundred miles of piping are laid down in England, containing over three thousand miles of wire. In Germany, also, there is an extensive underground system, which, instead of consisting, like the English lines, of a large number of wires laid in pipes, resembles a submarine telegraph: a number of wires are formed into a cable, which is served with tarred rope and armored with galvanized wire, after which it is laid in a trench under the public roads or highways, and the trench filled up with bitumen. In some of the cities of the United States, also, underground telegraph wires are laid in pipes. Underground telegraph wires, however, cannot be worked at the speed that aerial lines are capable of, on account of the static induction existing between them and the earth, which is greatly increased by their close proximity to the latter, and which tends to retard the signalling currents.

177. *Are underground lines suitable for telephonic circuits?*

When properly laid in twisted pairs, and carefully encased, telephone circuits in cities may largely be placed underground. It is, however, evident, from the fact that telephone wires, even when comparatively a long distance apart, interfere seriously with each other by the development of induced currents and other disturbing agencies, that such interfering influences would be considerably amplified in their strength and scope if the conducting wires were for a great distance placed as close to each other as would be necessary in an underground system. The near presence of the earth, moreover, exercises a retarding effect on the telephonic currents, causing them to become indistinguishable when the length of the underground conductor is about twenty miles. A partial remedy for both of these annoyances is to arrange the conductors in metallic circuit, especially when the two wires of the circuit are twisted together. Other remedies have been proposed, and have met with more or less success.

A great difficulty in the way is the enormous expense contingent on a first-class and thoroughly well-constructed underground system, especially in a city-system of short lines which have to be tapped at many points. The expense, though, would be nearly all first construction, as, when once properly laid, the wires would be secure from the effects of wind and weather; underground construction in cities, where practicable, is therefore to be advocated for its greater immunity from elemental disaster. In Paris, all the circuits have a metallic return, and are extended upon supports arranged upon the walls of the city sewers, which are spacious subterranean vaults.

It is now customary to arrange the telephone wires of American cities in cables—for example, of lengths varying from half a mile to a mile—and run these cables underground to a number of central points, such as courtyards or areas surrounded by houses, from which central points they may readily be extended to the surrounding buildings.

In 1882 the earliest systematic arrangement of subterranean telephone circuits was constructed and put in operation in Boston, Mass.

It was undertaken by the American Bell Telephone Company, and the construction is upon the following plan: Cables carrying multiple conductors are laid in iron tubes, which are embedded in the earth and extend in sections between a number of vaults, cellars, or working chambers. The several wires are brought out from these cellars at various central points, and radiate to the different sub-stations which are adjacent to such central points. In the prosecution of this design a trench is excavated about four feet deep in the middle of the street, and is paved with a layer of common hydraulic cement five or six inches thick. Upon this bed is laid a number of three-inch wrought-iron pipes, jointed together by sleeve couplings, screwed on by means of gas-thread, each of the joints being served with red-lead and thus made water-tight. A second thick layer of cement is then applied, and upon that a second layer of pipes is laid. The cement is then laid on and over the upper layer of pipes so as to embed the whole of them and cause them to be completely impervious to moisture. At or near each street intersection a vault is built of brick, the bottom of which is deeper than the lowest point of the trench. The series of pipes from either side enter these vaults, and in them the wires can be inter-connected, interchanged, and manipulated as may be found desirable.

Two routes are led from the Central Telephone Office.

The several vaults, in addition to being carefully and massively walled, are further protected from moisture by pouring hot pitch between each course of brickwork and the surrounding earth. As each pipe is laid a strong iron wire is threaded through it, so that when a line of pipe is complete between any two working vaults a continuous wire is also inside that pipe between the vaults, and by attaching groups of insulated wires or cables to this threaded wire they can be drawn through from vault to vault.

Iron, terra-cotta, or cement-lined pipes, have since then been much used as ducts; and within these are laid cables having a protecting sheath of lead mixed with tin.

The wires can be brought out by running lateral branches from the vaults into adjoining cellars or courtyards, and from these run tubing of an ornamental character up the side-walls of the surrounding buildings, and thus distribute the wires to their several termini. Another plan, and one likely to be adopted, is to erect a high hollow pole or column near the man-hole of the vault, run the wires up through this column, and from the top radiate them to their different destinations.

In still other cases, it has been found possible to run lateral branches, exactly as in gas distribution, from the main duct, directly into the cellar of the subscriber's station.

There were at the beginning of 1891 as many as 54,690 miles of telephone wire underground in the cities of the United States; New York, Chicago, Boston, Brooklyn, Pittsburgh, Baltimore, and Washington having by far the larger amount; their respective amounts being in the above order.

Many of these underground lines of course, as was expected, show quite perceptibly a sluggishness of operation and a slight indistinctness in the reproduction of articulation, which is evidently due to retardation, and which becomes intensified when the lines are connected through the Central Office switchboard with a longer line.

178. *What is meant by the term retardation?*

Retardation is the technical term given to a certain sluggishness of action which is observed when electrical currents are sent into long lines, particularly long covered wires, such as underground wires or submarine cables, because such wires are much nearer the earth than overhead lines. It is caused by the inductive action which arises between the conductor and the earth.

We have seen that an electrified body has an influence on all conducting bodies in its immediate vicinity, causing them to exhibit signs of electrification. This is a case in point. The current sent into the conducting-wire attracts by this induction, through the insulating covering, an opposite electricity from the earth ; and this opposite electricity, in turn, attracts the current passing in the conductor, and tends to hold it where it happens to be—in short, to transform it from dynamic or current electricity to static or resting electricity. Thus we see that the first part of every current sent is, if we may so speak, held or detained by the cable to balance the induced opposing electricity of the earth, and it is not until the conducting-surface of the wire is charged that any current can make its appearance at the distant end. Signals are thus delayed, and the delay experienced is called retardation.

As overhead lines are so much further from the earth, they are much less troubled by electro-static induction and its effects, and it has been estimated that in this country the charge retained by an overhead line of from thirty to fifty miles long is approximately equal to that of about one mile of ordinary submarine cable.

179. *How are the conductors in submarine cables ordinarily insulated?*

Only three substances have been found suitable as insulators for submarine cables—gutta-percha, india-rubber, and Hooper's material, which is india-rubber peculiarly treated. Of these gutta-percha has been and is most frequently used, on account of its well-known durability, being practically indestructible under water. It is not so good an insulator as india-rubber, and, inasmuch as it loses considerable of its insulating power by heat, it is, in warm climates, to a great extent superseded by india-rubber, especially that of Hooper.

At least three layers of the insulating medium are always used and are necessary. The insulation of cables ordinarily improves after they are laid, all things being equal. The insulation, per knot, of the Atlantic cable of 1866, which is insulated with gutta-percha, is 340,000,000 ohms; that of the French cable of 1869, from Brest to St. Pierre, insulated also with gutta-percha, is 235,000,000; while the cable laid in the Persian Gulf in 1868, and insulated with Hooper's india-rubber, attained the wonderful insulation of 3,900 megohms per knot. Even this has since been exceeded by cables of later date, insulated with the same material.

180. *What is the general construction of a submarine cable?*

Submarine cables are usually constructed by embedding a certain number of copper conducting wires—which may be either single wires or a strand of several small wires—in a good insulating material, such as gutta-percha or Hooper's india-rubber, applied in successive coatings. This, again, for protection, is surrounded with tarred hemp, and an armor, consisting of several strands of large iron wire, is wound outside of all. These iron wires, in several long deep-sea cables, are also covered with tarred hemp. The Atlantic cable of 1865, for example, which is shown in section in Figure 68, contains a central conductor consisting of seven copper wires twisted together. This is covered by four layers of gutta-percha, while between each layer a compound is applied which not only aids the insulation, but tends to unite the gutta-percha layers with each other. This is known as Chatterton's compound. Its component parts are gutta-percha, resin, and wood-tar. This core is then covered with a layer of hemp in five strands, well served with a compound of Stockholm tar, pitch, linseed-oil, and beeswax. The whole is then covered by ten strands of charcoal-iron, each strand covered with hemp. Thus the copper wire is a conductor, the gutta-percha and Chatterton's compound being for insulation, and the hemp and iron wire for protection.

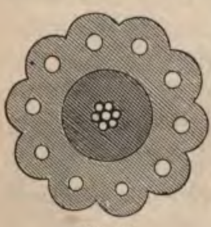
Fig. 68.

181. *Can the telephone be operated successfully over long bmarine cables?*

is recorded by Du Moncel, in his work on the telephone, that speech has been perfectly transmitted and reproduced between Guernsey, an island in the English Channel, and Dartmouth, a town on the coast of Devonshire, a distance of sixty miles. W. H. Preece has also successfully conversed over the Dublin and Holyhead cable, a distance of sixty-seven miles. M. Herz, by his improved arrangement of circuits and telephones, is said to have conversed easily between a point on the French coast and Penzance; and other electricians and experimenters have communicated between Calais and Dover with more or less success.

In 1889 the La Plata River was crossed by a telephone cable uniting the cities of Buenos Ayres and Montevideo; and this cable was in circuit with overhead bronze wires, making the total length of line 186 miles.

The most recent success in this branch of communication, however, is the London and Paris line, completed in the early part of 1891.

This is, of course, composed of sections of land line at each end, and a channel cable uniting them. The French land line is about 204 miles long, and is built of copper wire weighing about 600 lbs. to the mile.

The English land lines are 83 miles long, and weigh 400 lbs. to the mile.

The cable has four conductors, each composed of a strand of seven copper wires, weighing 300 lbs. per knot. The dielectric is gutta-percha, weighing 300 lbs. per knot, and the length of each conductor is approximately 21 knots. The telephone works well through the metallic circuits of this line.

Thus we see that for moderate distances the telephone can be operated over submarine cables, even though connected with land lines at both ends. But through long cables, it is very doubtful whether commercially the telephone can ever be successfully operated, or rather whether a practical cable can ever be constructed to meet the peculiar conditions.

CHAPTER XIV.

OFFICE-WIRES, AND FITTINGS AND INSTRUMENTS.

182. *What wire may be used in fitting up an office, and how should it be attached to the walls or ceilings?*

It is too frequently the practice with telegraph employees in general to use No. 14 covered copper wire, and to stretch the wires loosely in and along the ceiling in any way so as to get them in; but it is as easy (and much more satisfactory when done) to do a job of wire-running in a tasteful as in a slovenly manner, although it requires great skill and experience to run the inside wires of a telegraph or telephone office in a manner both useful and ornamental.

To do this it has been found in practice that it is better to use braid-coated copper wire of a gauge not exceeding No. 18. To have this wire colored often gives a very tasteful effect, especially when colored red. But, in any case, No. 18 is sufficiently large to serve every practical purpose, while it is much easier to handle and gives a better general effect when strung. The wires when chosen should, if numerous, be strung through cleats of black walnut pierced with the required number of holes, which should only be large enough to let the wire pass through easily. If more than fifty wires are to be put up it will often be found necessary to bore more than one row of holes and run the wire two or more tiers deep. Each cleat should be screwed to a base board of hard wood, which is to be screwed to the ceiling. This is to give a greater purchase to resist the strain of the wires when pulled tight. The wires should be secured with a half-hitch to the first cleat, and, when ssed through all of them, tightened up, so as to take out *all* the slack, and anchored by another half hitch at the last cleat, which should be about two feet above the switch-board, if one is used. Instead of then bringing them straight down to the switch it is better to coil them into loose spirals, as it adds to the general effect and also gives slack if any wire should break. If only two wires are to be arranged it is sometimes convenient to string them on opposite sides of a row of porcelain knobs till they reach the instruments.

Where extremely powerful currents are used—as, for example, those employed by the Gold and Stock Telegraph Company—the office-wires need a much more effectual insulation than paraffined cotton, and kerite or rubber covered is generally employed. In large Western Union offices the wires are usually secreted as much as possible.

Close to the entering point of a building a lightning-arrester should always be placed, which should be connected to a very efficient ground wire. Every wire entering the office ought to pass through the lightning-arrester. The lightning-arrester ground should never run to a lead pipe or to the same ground that other wires are led to.

A favorite method which has lately been much employed by telephonic constructors, and which is excellent, is to run the wires clear down to the switch-board in twenty-five or fifty wire cables. This gives a very clean and neat appearance to the office. It is a very good plan also to keep the wires out of sight altogether, which may be done by ranging them in troughs along the floor and bringing every wire to the switch-board at its rear.

183. *How should a ground-wire be constructed in order to insure efficiency?*

Three distinct services are required of the ground-wire in practical work—namely, to act as the terminal of main lines, to attach to lightning-arresters, and to use for testing purposes.

In a well-appointed office three separate wires will be used, one devoted to each of these purposes, and all running to earth at different points.

Too much attention can never be given to this all-important subject. It is, indeed, the groundwork or basis of all telegraph or telephone line-construction, and it may be broadly stated that no matter how well a wire may be strung, or how perfectly the instruments and batteries are connected, if the terminal grounds be imperfect the working will also be imperfect.

No better ground can be secured than the iron water-pipe of a town or city, and this should, if possible, always be secured. An iron gas-pipe will, however, serve a very good purpose, provided the connection be made outside of the meter; this precaution is necessary because the meter is sometimes removed, and because the joints of gas-pipe are frequently made in red and white lead, which substances are non-conductors. In the case of water-pipes the water inside aids the pipe in its conducting powers. If neither water nor gas pipes can be found, a plate of metal, not less than two feet square, may be provided, the metal either being tinned or galvanized iron or copper. This should be buried edgewise in ground which is always damp, and the ground-wire attached to it by riveting and soldering. We have known good ground-wires being formed by attaching wires to a pipe of a steam-heater, first brightening the pipe. If both water and gas pipes are at hand the ground-wire should be securely attached to both, so that if one be cut or broken the other will remain to preserve the continuity of the line. Lead gas-pipes should never be employed; they are dangerous. A discharge of lightning has been known to melt a lead gas-pipe attached to a ground-wire and to set fire to the escaping gas.

We are aware that it has been common to ridicule the idea of insulating the ground-wire; it is nevertheless true that a terminal ground should always be insulated.

This is both to protect it and to keep the battery current uniformly at the same strength. If a ground-wire be not insulated it is likely to corrode at any point at which it may find earth between the main ground and the battery.

To make an excellent connection about six feet of bright, bare copper wire should be taken, about No. 16 or 18 gauge; the gas or water pipe having been filed clean for a length of about three inches, the wire should be carefully, tightly, and regularly wound round, and as the end of the wire approaches it should be interwoven among the convolutions and drawn tight; when about eight inches is left unwound it should be well spliced to the insulated wire leading from the instruments and line.

Both splice and coils should then be soldered. A clamp is in some cases used, but it is not to be recommended, as screws generally work loose in some mysterious manner. In offices where many wires centre—for example, the central office of a telephone system—it is desirable that as many independent ground-wires should be constructed as can be readily done.

For *lightning-arrester grounds* a very large wire should be run directly from the lightning-arrester to earth, at the nearest convenient point, and connected in the way already described.

Testing grounds may generally be constructed in the same manner. It is under this head that the ground-wires of a way telegraph-office come. For such an office it is well enough to use the same wire also as a lightning-arrester ground.

It may be remarked that every telegraph engineer must have noticed the extreme difficulty of making a good earth-connection when wanted, and the perverse facility with which a ground will come on a line when it is not wanted. In short lines care must be taken to have the earth-plate or pipe of the same metal at both ends, or a current will be set up, arising from the action of the damp earth on the two dissimilar metals when united by a conductor. It is well to dispense with an earth return altogether in extremely short lines, using a wire so as to form a metallic circuit.

184. *What is the best arrangement of instruments in a telegraph office operated on the ordinary Morse system?*

In an ordinary way-office the apparatus consists of the following instruments: a *relay* and *key* in the main-line circuit, a *sounder* or *register* and *local battery* in the local circuit, and a *switch* and *lightning-arrester;* the latter is often combined with the former.

The switch, or, if there is none, the cut-out, is placed on the wall and the office-wires led to it. If it is a Western Union pin-switch the leading-in wires are led to the binding-posts connected to the upright metallic bars, where they remain open until the pins are inserted. Two other wires, called the instrument-wires, are led, from the side binding-screws, under the table; and after the relay, sounder or register, and key are placed in position, holes are bored through the table near to the main-line binding-posts of the relay (these are usually placed at the right-hand end of the relay); the key is then fixed in place, holes being bored through the table for its legs, and the wire connected. The order of the instruments is indifferent; that is, it does not matter which comes first or last. One of the main wires is led to one leg of the key, and there fastened to it. A short wire is run from the other leg of the key to one of the relay binding-posts. The other main wire is then connected to the remaining relay binding-screw, and the main circuit is complete, the order being as follows: line wire, key, relay, line wire. The pegs are now inserted in the switch. The local circuit includes the local battery, the relay-points, and the sounder, or register, and is run as follows: After setting up the local battery, which usually consists of two cells, run a wire from one pole, say the copper, to one of the binding-screws of the sounder, which, like the relay, has holes bored near it; then another wire from the other sounder-screw to one of the local screws of the relay (these are usually at the left-hand end of the instrument), and a third wire from the other relay local screw to the other pole of the battery. It is perhaps almost unnecessary to say that these office connections must always be made with covered wire, and particular care should be taken to keep all screws tight.

The sounder, or register, is most conveniently placed near the centre of the table, and if a register is used the paper-reels should be fixed one at each end—one to deliver the paper to the register and the other to receive the paper as it comes from the register; the relay is preferably placed at the left of the register, and at the rear of the table, while the key is placed at the right, also at the rear of the table, so that an operator, when sending, has the breadth of the table whereon to rest his arm. A terminal station is arranged on the same principle, but, as only one wire comes in for each line, the other end goes to the main battery and ground. For example, the wire entering the office is led to the switch-board, thence to the relay, thence to the key, after which it is carried to the battery, and the other pole of the battery is connected to the ground.

185. *What is a switch-board?*

It is a piece of apparatus adapted for the convenient and easy cross-connection or interchange of circuits. It is made use of almost universally in telegraph offices where there are more than one wire. By its use different circuits are connected together, circuits are divided, testing operations are carried on, batteries are readily connected, disconnected, or changed, and the wires are connected to any desired instruments. The varieties of switch-boards are very numerous, but they are nearly all constructed on essentially the same principle. This principle is embodied in the *universal switch*, which is, briefly, a frame or base-board of hard wood or some suitable non-conducting material, on which are fixed

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two sets of metallic conducting strips, bars or wires, crossing each other at right angles, but completely insulated from each other, and means for connecting any conductor of one set with any conductor of the other. The chief difference between the numerous forms of switch-board is in the methods adopted of making such connection.

The most familiar switch-board in this country is the standard Western Union pin-switch, which is shown in Figure 69, and which is almost too well known to require description.

On the front of the board are placed any required number of vertical brass bars in pairs. Between each pair of these upright bars is placed a row of brass discs, while all the discs on each separate horizontal line are metallically connected by means of a copper wire, thus representing the horizontal series of the bars, the vertical brass bars being the opposite series. Each disc has a semicircular hole cut in its edge at each side, and each bar has the corresponding semicircle cut opposite the hole in the disc, so that a metallic plug put in any of the holes presses against both the upright and cross-bar, thus making the connection. In telegraphic practice the incoming wire is led to the binding-screw connected to one of the upright bars—for example, No. 1—and the outgoing wire connected to No. 2, and so on, until all the wires are provided for. The instruments are similarly connected to the binding-screws of the horizontal bars, or the wire and discs representing the same. It is, then, obvious that to connect any line with any instrument all there is to do is to put in plugs at the point of intersection. For instance, if No. 1 line is to be connected to No. 1 instrument, we put a plug in the intersecting hole between the first upright bar and the first disc, and another in the hole between the second upright bar and the disc immediately below the first one, or the second one down the column. In this class of switch-board the lightning-arrester is usually placed at the top, in the shape of a brass bar connected to a ground-wire, and placed horizontally across all the upright or line bars, as close as possible to them without touching. This can also be used as a testing ground by means of two pin-holes drilled through it and through the edge of the upright bars on each side. To put on a ground a pin must be inserted on the necessary side.

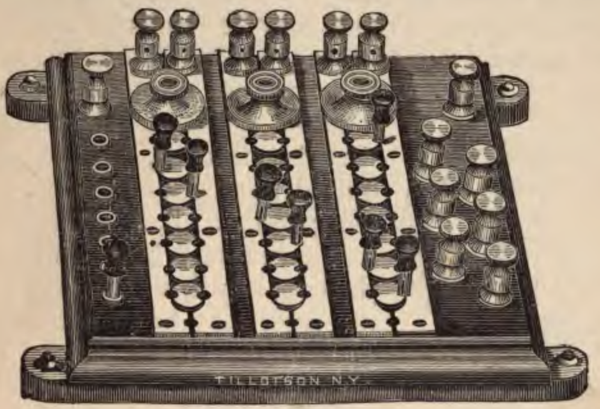
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Fig. 69.

In the figure line 1 is shown connected with its instruments by means of two plugs inserted between the upright bars and the discs; line 2 is similarly connected with its own instrument, and line 3, in addition to being connected with its instruments, is grounded by the insertion of a plug in the upper right-hand hole.

When such a switch is used for telephone service the horizontal bars are chiefly used as connecting strips between any two circuits, and in that case each line is attached to only one vertical strip, thence to instruments and ground.

Since the introduction of the telephone the importance of the switch-board has greatly increased, and many improvements have been invented, chiefly relating to the modes of connection and manipulation.

186. *Describe briefly other switches in use.*

Many small switches or circuit-changers are used for cut-outs, ground-switches, battery-switches, and kindred purposes. They are usually either plug or button switches.

The *plug-switch* is simply two or more brass plates with holes drilled between them, so that by the insertion of a metal plug any two or more plates, with the circuits attached to them, may be connected together.

The *button-switch*, as shown in Figure 70, consists of a lever, A, pivoted at one end to a screw, to which the main-circuit wire is attached, and of any required number of buttons, or contact-points, as B, C, each connected to a screw and branch wire below the base-board, and to any of which the lever may be swung, thus connecting the circuit to the branch required.

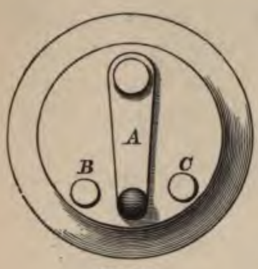

Fig. 70.

Several such levers may be connected together by an insulated cross-bar and worked by the same movement; these are called compound switches. Special forms of switch are also used in connection with telephones; these are popularly known by the names of *secrecy* and *automatic* switches. The first of these was devised on the baseless theory that every person would be on the lookout to listen to the conversation of others, and is designed to obviate such occurrences. It consists in devices whereby a telephoner, by turning a lever or a hook, opens or breaks the line in the direction in which he is not about to converse, and at the same time connects a temporary ground, completing the circuit through his telephone in the direction in which he does intend to converse.

The automatic switch is one in which the removal of the telephone changes the circuit from the alarm to the telephone, and is in general use. The principle is clearly represented by Figure 71, in which, when the telephone is in its place on the hook, the line is connected through the signal-bell, but when the telephone is removed from the hook the latter flies up under the influence of the retracting spring and connects the line to the telephone branch.

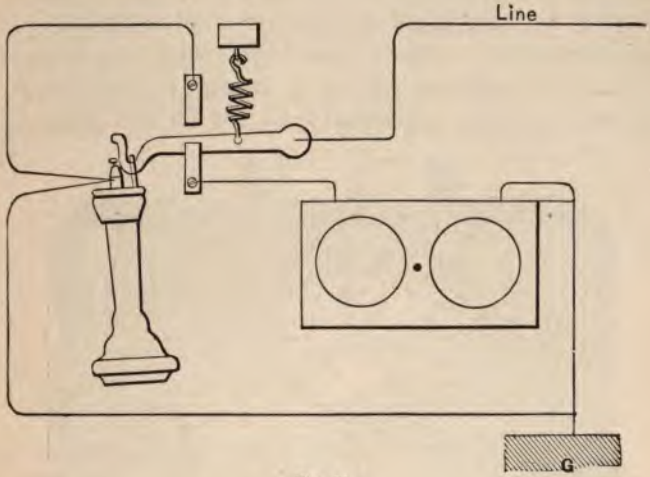

Fig. 71.

187. *What is meant when we speak of a loop?*

A *loop* is the technical name applied to a wire which branches out from the main circuit to some other point (such, for instance, as a branch office), and returns to the main line again at or near the same point at which it left it. Loops may be either permanently connected to the main line—as when a town is situated a mile or two one side of the main line, and the line-wire is led from the main line to the town and back again to the main line on the same poles—or they may be so arranged as to be included in the circuit of any desired line. This is usually the case when the loop starts from an office. It is then led from the switch-board and can easily be switched into any circuit.

188. *What is a lightning-arrester?*

It is an apparatus designed to protect telegraph offices and their instruments and inmates from injury by atmospheric electricity, which, when it charges the line-wires, follows them into the offices during lightning storms. If unprotected the fine wire coils would often be burned and the operators might also be injured, fatally or otherwise. The principle on which nearly all lightning-arresters are made is that lightning, being the discharge of electricity of very high tension or electro-motive force, will take a short route, even of high resistance, in preference to a longer one of much better conductivity, its chief object being apparently to get to the ground by the quickest possible way, no matter how difficult that way may be. It will, therefore, leap over an intervening air-space, or force its way through a resistance that acts perfectly well as an insulator to the voltaic current, which is of much lower tension. Depending upon this principle, lightning-arresters are frequently made by connecting each wire, as it enters the office, to a screw with a sharp point, and adjusting the sharp-pointed screws connected with all the wires as close as possible

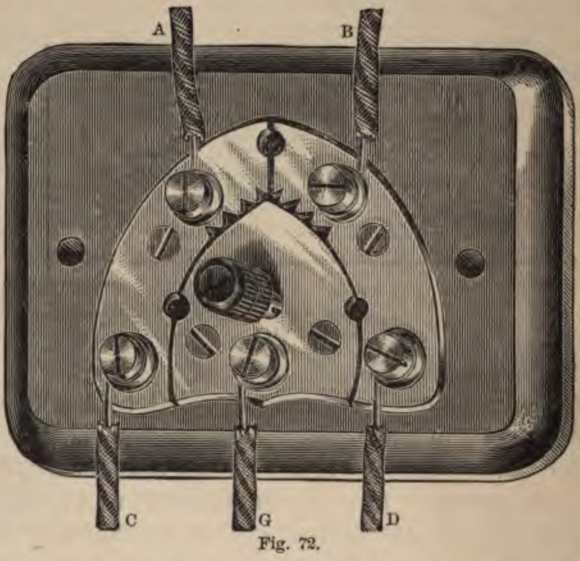

Fig. 72.

to, without allowing them to touch, a metal plate, which must be connected to the ground-wire. As there is such a short distance between the points and the plate, the lightning, when it enters, jumps over the space and escapes to the ground. A lightning-arrester embodying this principle is shown in Figure 72, A and B being the line-wires, which, as shown, are attached to segmental metal plates ; C and D are wires leading from the plates to the instruments, and G is a wire leading from the central heart-shaped plate to the ground.

Another arrester, much used in country offices, is made by placing two brass plates, connected to the lines, upon a larger brass plate connected to the ground, and separating them only by a very thin sheet of non-conducting material—paper is the most frequently used. Such an appliance is shown in Figure 73.

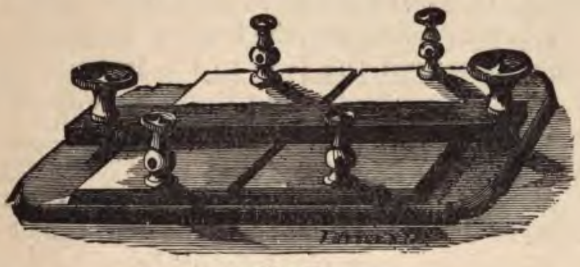

Fig. 73.

Now, when lightning strikes the wires and enters the offices it forces its way through the insulating material to the ground-plate below, thus effecting its escape. The lightning-arrester must invariably be placed between all the other apparatus and the line, so that any charge of atmospheric electricity coming in on the wires may be afforded every facility to pass to earth before arriving at the electro-magnets of the instruments.

189. *What is a cut-out, and what kind is preferable for a way-station?*

A cut-out is a switch or circuit-changing device used in telegraph offices for the purpose of disconnecting the instruments from the line, leaving, at the same time, the line perfect and continuous, so that messages can be sent and received by the offices on either side of the station whose instruments are cut out. They are of two general classes. First, those in which the instruments are merely short-circuited; that is, a shorter path is given for the current than the route through the relay, by connecting the incoming and outgoing lines by a button or plug. Secondly, those in which the instruments are totally disconnected from the line; that is, when cut out, no metallic connection is left between the line and instruments. The latter is by far the most preferable, as it removes the instruments from all possibility of danger from atmospheric electricity. Where the Western Union pin-switch is used the instruments may be cut out at night, or, when leaving the office temporarily, by connecting the two upright bars by one or more extra pins or plugs, leaving the two pins connecting the instrument-loop in place.

When so arranged the loop to the instruments connected with the cross-strips or discs is short-circuited. This is a type of the first class mentioned. It may, however, be converted to a cut-out of the second class by simply placing both of the pins connecting the instrument-loop to the upright on the same disc, thus making a short-circuit in and out of the office, and at the same time opening the wire leading to the instrument. A simple form is shown in Figure 74; the line-wires entering are connected to the terminals, L, and the instrument wires are connected with the binding-screws, B, B. When the metal bars, S S, are swung on the terminals, B, the circuit includes the instruments; when both bars are turned on the middle plate, C, the instruments are cut out, and the circuit is completed through the plate, C.

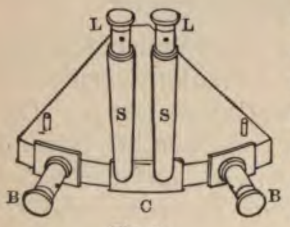

Fig. 74.

The most popular and universally employed cut-out for way-offices where there are but one or two wires is the plug and spring-jack cut-out. The plug is a double wedge made of two pieces of brass, separated by a thin layer of insulating material.

The spring-jack, as shown in Figure 75, consists of a brass spring brought very firmly against a stationary pin, the spring being permanently connected with one line-wire and the pin with the other. Each of the two brass pieces composing the wedge is attached by a flexible conductor to one of the instrument-wires, so that the two together form actually a loop that can at will be inserted into a spring-jack, which is always in the line-circuit.

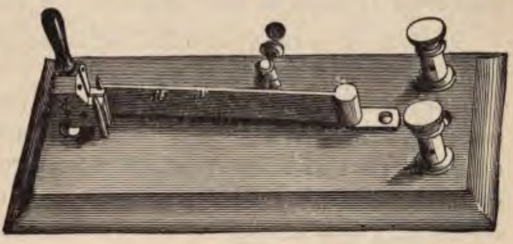

Fig. 75.

190. *What is a spring-jack?*

It is an arrangement for readily inserting any loop into a line-circuit, and is operated in conjunction with a wedge-connector.

It was invented first by Messrs. Cooke and Wheatstone, and patented by them for use in their needle-telegraph system as early as 1837. In 1855 it was adapted for use in connection with switch-boards, considerably modified in form and improved by G. F. Milliken, of Boston, who also employed it as a cut-out. The two line-wires are run to two binding-screws at the top of a base-board, and from these are connected, by means of small wires below the board, one to a strong brass spring, the other to a brass pin, against which the spring strongly presses by its elasticity. The instrument-wires, connected into a wedge or plug such as that described in the last answer, and fitted with a rubber handle, are inserted between the two surfaces, and by the spring and the constant rubbing a good connection is insured. Somewh varied in form, this device has come into extensive us both in telegraphic and telephonic service. Any contrivance where a wedge is employed to connect or disconnect instruments, or to change a circuit by insertion between, or withdrawal from, spring contacts, may properly be termed a spring-jack.

191. *What is a relay, how is it made, how used, and from what does it derive its name?*

A relay is an instrument included in the line-circuit at each station, which acts by the influence of the electric currents on the main line to bring into play a battery, called the local battery, at the receiving station, and, by closing the circuit of such local battery, to work a sounder or register with much greater strength than it could be worked by the main-line current, which is, of course, much weakened by the distance it has to travel, or by the resistance of the long line-circuit it has to traverse, as well as by the leakage due to imperfect insulation. It is obvious that such currents, though too feeble to work the heavy armature-levers of a sounder or a register, may yet be perfectly able to move the light lever of a relay-magnet, and thus close the local circuit. It is precisely like a key circuit-closer, with the exception that it is not worked by hand but by the line-current. Professor Wheatstone was the first telegraph man who employed the principle, although, instead of using an electro-magnet to operate the circuit-closer, he employed an electro-magnetic needle, deflected by being hung in the centre of a coil; the needle was provided with a point of metal which closed a circuit and rang a bell by dipping into a cup of mercury that formed one electrode of an open circuit, the needle being the other.

The relay of the present time is made as follows: The electro-magnet is formed of two spools of fine, silk-covered magnet-wire, usually No. 32 gauge. These each enclose a core of soft iron, and both cores are united at one end by a soft-iron yoke or heel-piece. The wires of the two coils are joined together, so that one coil follows the other in the line-circuit, and the direction of the wire forming the coils must be so that if the cores were bent up, and thus constituted one straight bar-magnet, the wire would be in the same direction throughout. These coils are placed upon a flat base of wood, and the ends of their wires are connected to two binding-screws, usually placed near one end of the wooden base. The coils are also fixed with the yoke which unites them to face the same end. The two coils together will, on an average, have a resistance of about one hundred and fifty ohms. In front of the free end of the cores is hung on pivots a light brass lever, carrying a light soft-iron armature, which is immediately opposite to the core ends. This lever vibrates between, and is limited in its movements by, two set-screws which are set in a brass frame near its upper end. The limit-screw which the lever strikes when drawn up to the cores and coils that form the electro-magnet is, by means of the brass frame, one contact-point or terminal of the local circuit. The back limit-screw is tipped with some non-conducting substance, so that when the lever falls back the local circuit is again opened. The lever itself is connected by its pivots or otherwise to the other terminal of the local circuit. The wires leading from the lever and from the contact-point above are led under the base to two other binding-screws, and there connected to the local battery wires. A retractile spring is attached to the back of the armature, and tends to draw it back when not attracted by the magnet. A screw is also fixed at the back of the magnet under the yoke-piece, by which also the magnets may be withdrawn from or advanced toward the armature.

Figure 76 shows a relay constructed in the manner described, and is a type of nearly all the Morse relays in use in the United States.

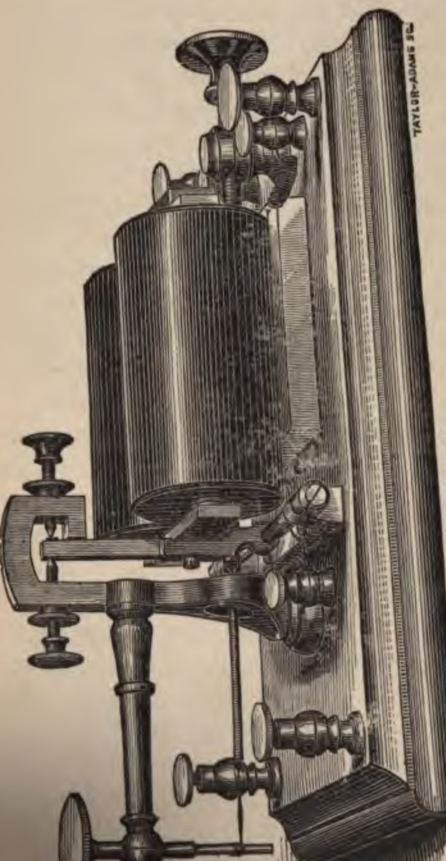
TAYLOR-ADAMS SC.

Fig. 78.

To work a relay properly the armature movement should be very small. This is adjusted by the limit-screws at the top of the armature-lever. The play between these screws should never exceed one thirty-second of an inch; and the adjustment should be so made that, when the armature is attracted, a piece of thick letter-paper can be passed between the ends of the cores and the face of the armature. There is another adjustment which is more important, and its proper management, especially on badly-working lines, is one of the best tests of a good operator. It consists in adjusting the retractile spring by means of a screw to which it is fastened. To it, it is best to advance the magnet nearly close he armature, so as to take full advantage of the gth of current, and then turn up the spring, that ay recoil promptly when the main circuit is opened. he armature sticks or lags when the spring is suffi- ly tense, the magnets must be screwed a little back.

The name relay is derived from the analogy which the function of the instrument bears to the change of horses and consequent renewal of power at the different stages of a long journey.

Another form of relay is much used in Europe and other countries, and, to some extent, on special systems in America. It is called the polarized relay.

192. *Describe briefly the polarized relay and its method of operation.*

A *polarized relay* is one in which the retractile spring which serves to withdraw the armature-lever from the connecting point of the local circuit when the circuit is opened is replaced by the attraction of a magnet. As the moving armature is very light, and as the attraction of one pole is assisted by the repulsion of the other, the polarized relay is very sensitive. The Siemens polarized relay is the best known of its class.

Its principal features are represented in Figure 77. It is composed of a steel permanent magnet bent to a right angle—that is to say, till it is shaped like two sides of a square. One end is then a north and the other a south pole. On one end—the end that lies flat, or the base of the square—an electro-magnet is screwed, the heel-piece of the electro-magnet lying across the permanent magnet. The extreme end of the other arm, or the upright side of the square, is forked, and in the fork is pivoted a small soft-iron bar, which acts as the lever and armature of the relay.

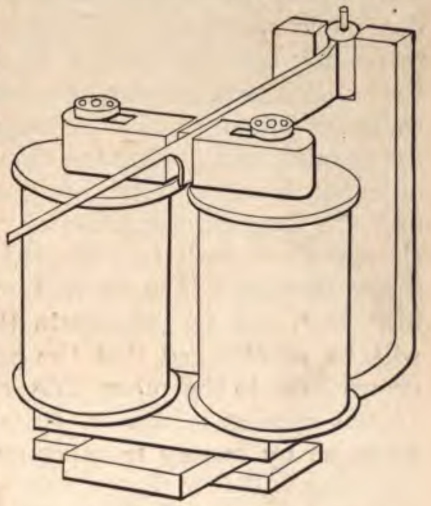

Fig. 77.

This turns horizontally on its pivot and works between the poles of the electro-magnet, which terminate in flat pole-pieces of soft iron. The armature is extended out by a slender tongue, the motion of which is limited by a metallic screw forming the local connection on one side, and a non-conducting screw on the other side.

The two soft-iron cores of the electro-magnet have by induction become charged with magnetism of the same polarity as the end of the permanent magnet to which they are fixed—say north; and the armature is similarly charged with the magnetism of the end to which it is fixed—south, of course; so that, working between the two poles of the electro-magnet, it is, if placed in the centre, attracted equally by both of them, but if moved the smallest distance to either side it will be attracted to that side. If a current of electricity be sent through the relay-coils, one of the poles has its induced north magnetism strengthened and the other has it weakened or neutralized, because the current tends to set up an independent magnetism of its own in the electro-magnet, in one leg agreeing with, and in the other leg opposing, the induced permanent magnetism. Now, if the relay is to be used in a system of telegraphy which is worked by opening and closing the circuit, the relay must be so adjusted, by altering the position of the iron pole pieces and the limit-screws, that when no current is passing the armature shall be attracted to the insulated limit-screw strongly; if a current of suitable direction be now sent, the magnetism in the electro-magnet cores will be so changed that the armature will be smartly drawn over to the other side, closing the local circuit. If the current is not of suitable direction it can be made so by merely transposing the entering and leaving wires. When the current ceases the armature will at once be drawn back to the original side by its superior magnetic strength. If, however, the system of telegraphing used be that of sending currents of alternate direction, the armature must be adjusted as nearly as possible in the centre between the poles of the electro-magnet, and in that case it will stay on the side to which it was last attracted until drawn to the other side by the passage of a current of opposite direction.

193. *What is a Morse telegraph-key, and how is it made, connected, and used?*

The key used on the ordinary closed-circuit telegraph systems of this country is simply a device for closing and breaking the circuit of the main line, and thus producing the alternate charge and discharge of the electro-magnets of the relays included in such circuit. By making in this way the alternate breaks and closings of different length, number, and disposition, any required signal can be sent, and either recorded or sounded at any designated point. The key is constructed as follows: A metallic lever, four or five inches long, is hung upon a steel arbor between two set-screws attached to a metallic frame. It is movable vertically, but its play is limited in one direction by its anvil or front contact, and in the other direction by a brass set-screw by which the degree of play is adjusted. The anvil is insulated by a bushing of hard rubber from the frame. One wire of the main circuit is connected to the anvil and the other to the frame. Screw-legs are attached, one to the base of the frame and the other to the under side of the anvil. By these screw-legs the wires of the circuit are attached and the key is clamped to the table.

The lever of the key is fitted with a finger-piece of hard rubber or ivory, which protects the fingers of the operator from electric shocks. The contact-points of the lever and the anvil are generally made of platinum, as ordinary metals would be burned and melted by the electric spark which passes when contact is broken. Some advocates have, however, been found for steel points. A spring is placed under the lever, which keeps it away from the anvil when the former is not pressed down; and as there is then no connection between the two wires of the circuit, a switch or circuit-closer is attached, which, when the key is not being used, serves to connect the anvil with the frame. The key we show in Figure 78 is made as described and is of the most improved character; its lever is very light and is of fine steel forged in one piece with the trunnions. Keys are now made with binding-screws attached to their upper surface, so as to dispense with the leg connections.

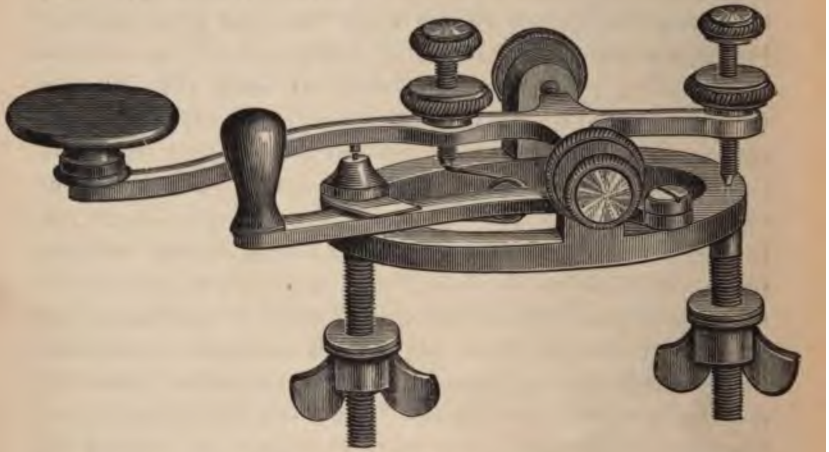

Fig. 78.

Keys are also made, and work excellently, with contact-points consisting of two metal discs, one fixed to the lever and one to the anvil. The upper disc is placed so that its periphery is at right angles to the lower one, and the point of contact can be varied, when necessary, by turning either disc a short distance round, both being adjustable.

This improvement was made by George Cumming, of New York.

In a way-station one wire runs from the key to the relay, the other wire from the other leg of the key to the switch-board or cut-out, and thence to the line. When the key is to be used the switch or circuit-closer is first opened. As soon as this is done the circuit is, of course, open, the anvils forming one end of it and the contact-point of the lever the other. The current, therefore, cannot pass, and the armatures of all the relays in the circuit cease to be attracted and fall back. The operator then alternately depresses the lever and allows it to rise under the influence of the spring, in correspondence with the signals of the Morse alphabet; and, in exact harmony with such movements, the circuit is closed and broken; the armatures of the relays in the circuit are attracted and withdrawn, and the strokes of the sounder—or, technically speaking, the dots and dashes of the register or recording instrument—are produced by the closing of the local battery circuit, which is operated by the movement of the relay armatures.

194. *Are any other keys in use besides the ordinary closed-circuit key already described?*

Yes; several others. What is called the *open-circuit key* is used on some lines, and is generally employed in most European countries. In general principles it resembles the key already described. The chief point of variation is that both back and front contact-points form electrical connections. When the key rests on the back contact the line is generally completed through the relay to the ground or out to the next station. When the key is depressed to the front contact the battery is connected to the line. Other keys are made to close on the back contact, thus opening the circuit entirely when they are depressed. Others, again, sometimes called pole-changers, or reversing keys, are constructed and connected to reverse the direction of the battery current at each alternate depression and retraction. An alternate-current key is easily constructed by fastening to a base of non-conducting material two springs of metal having finger-pieces of hard rubber. Over these, and pressing against the back of both springs, is a metallic bridge. The springs by their elasticity press firmly against the bridge. Immediately below the knobs or finger-pieces is an anvil of metal. One pole of the battery is then connected to the anvil and the other to the bridge, while one of the spring keys is connected to the line and the other to the ground. Now, when one key is pressed a current of one direction is sent to the line, and when the other key is pressed a current of the opposite direction is sent to the line.

195. *What is a sounder, and how is it connected?*

The sounder is a very simple instrument and requires no protracted explanation. It is generally used in short local circuit and is operated by the armature of the relay. On short lines, however, sounders wound with suitable wire are often connected in the main circuit,

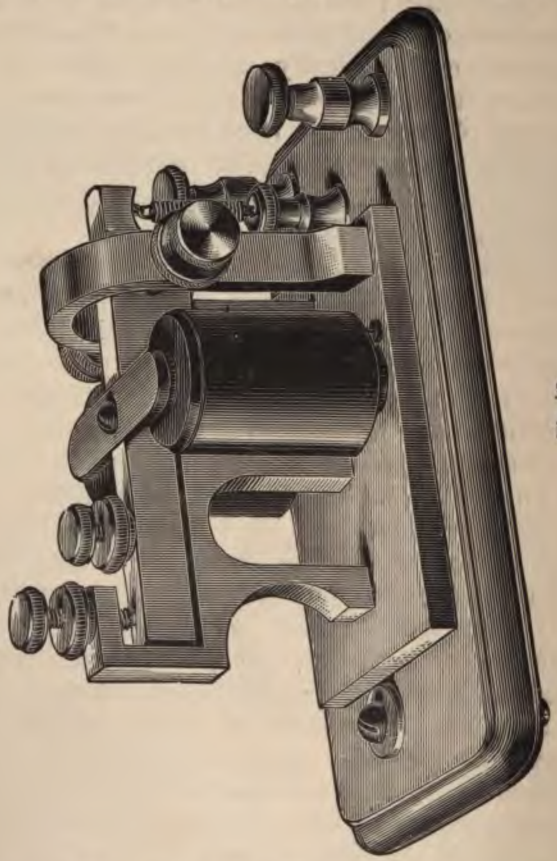

Fig. 79.

and the relay is then omitted. It is merely an upright electro-magnet screwed down to a base-board and fitted with a soft-iron armature which is provided with a lever working in adjustable pivot-screws. Its free end is limited in its stroke by two set-screws. The lower screw is set so that the armature almost touches the face of the magnet-cores, and the upper screw is set far enough away to give a sufficiently loud sound; a retracting spring is attached to the lever and pulls it back when it is not attracted by the magnet. The signals are given by the beats of the lever between these two screws, and the different signals are distinguished by the difference in sound between the down and up stroke of the lever and the duration of the strokes. The magnet, when used in a local circuit, is wound with No. 24 silk-covered copper wire, and has a resistance averaging about four ohms.

The sounder we show in Figure 79 is the Giant Sounder, designed by J. H. Bunnell.

When the armature of the relay is attracted by the closing of a key in the main line, the local circuit is closed by the relay contact-points, the sounder-magnet is charged by the local battery current, the armature is attracted, and the lever is smartly drawn down and the down stroke is made. When the relay armature falls back the circuit is once more opened, and the spring pulls the lever back, causing the up stroke. The sounder-stroke is much improved by screwing the instrument down to the table. One of the binding-screws must be connected to one pole of the local battery, the other to one of the local binding-screws of the relay.

196. *What is a register, and how is it connected?*

The register is the name given in America to the Morse recorder. It is made in several different ways, all of which, however, involve the same principles. The purpose of this instrument, which is represented by Figure 80, is to record the characters of the Morse alphabet on a strip of paper. It was the original idea of Professor

Morse to do this, and the sounder is a natural outgrowth and extension of this principle. Two objects are to be accomplished by the register—first, to record the characters; and, second, to draw the paper along so that the characters will be made in regular succession. To effect these results the paper, which is in the form of a roll near or over the register, is passed between a pair of rollers, *r*, which are revolved by a train of clockwork driven by a weight attached by a cord to the drum, W.

The clockwork is started or stopped by a brake, *a*.

The upper roller has a groove cut in it all the way around, so that the stylus, *p*, may readily emboss the paper by pressing it into this groove.

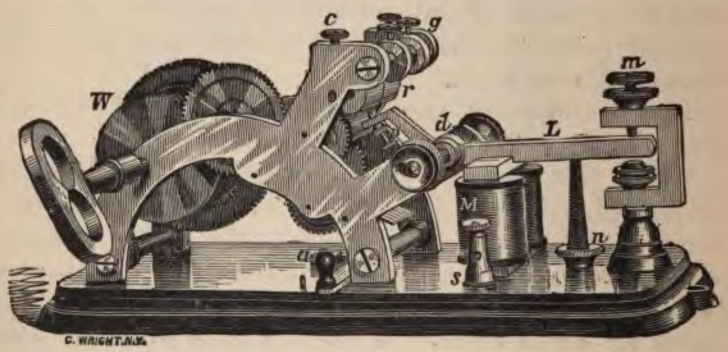

Fig. 80.

The electro-magnet, M, is placed upright; its armature is furnished with a long lever, L, and at the end of the lever is fastened a steel point, or style, *p*, which may be adjusted up or down by a set-screw.

The strip of paper passes through the guide, *g*, and between the grooved rollers. The steel point is adjusted immediately under the groove in the upper roller, and is on the under side of the passing paper.

A spring retracts the armature when no current is pass- just as in the relay or sounder. Every time the re- points are closed the register armature is attracted, and as the armature end of the lever goes down the style (being on the other side of the pivots, which are supported by set-screws) goes up, a mark is made upon the paper by the point, corresponding in length to the duration of the passage of the current. The magnet is wound with silk-covered copper wire of No. 23 or 24 gauge, and is ordinarily of about four ohms resistance. Two large cells of gravity battery ought to work it well. Main-line registers are sometimes employed for lines not exceeding in length twenty or thirty miles. They must, of course, be wound with much finer wire.

The register is not at present used to any great extent in America, having been superseded by the more simple sounder. In small country offices it may, however, be seen in all its glory. Had it remained in universal use it would probably by this time have developed into the ink-writing instrument, which is much used in Europe. The connections are made exactly the same as those of the sounder.

197. *It is required to connect a sounder and register with a three-point switch, so that either can be worked by the relay; how is it done?*

We will suppose the relay, register, and sounder to be already fixed upon the table and the local battery set up. Connect one pole of the battery to one of the relay local connections, and the other relay binding-screw to the lever-point of the switch. Attach one of the other points of the switch to a register binding-post, the other to a sounder binding-post. Then run a wire from the other register-post to the remaining sounder-post, and from there to the other pole of the battery, and it is done. To work the register the switch must

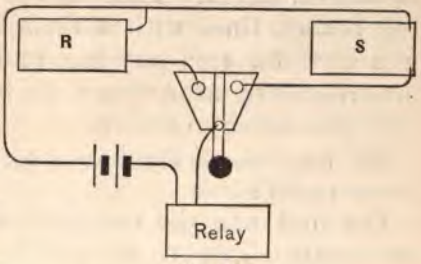

Fig. 81.

be turned to one point; to work the sounder, to the other.

This is shown in diagram by Figure 81.

198. *What are repeaters?*

Repeaters are peculiar arrangements of instruments and wires whereby the relay, sounder, or register of one circuit is caused to open and close another circuit, thus repeating or duplicating the signals sent on the first circuit, by the hand of the operator working a Morse key, on to the second circuit by the upward and downward movements of the instrument armature-lever, in the same way that a relay closes the local circuit of a sounder or register. The earliest ones were so arranged that but one side had facilities to repeat; and if the receiving operator desired to break he was dependent on the attendant at the station where the repeater was located to turn a switch whereby the repeating devices were transferred to his circuit. This had obvious disadvantages, and many automatic repeaters have been invented which do not need the services of an attendant, as by their use either side can send, either circuit repeating into the other at will. Repeaters are used to connect two circuits together to work through which are ordinarily operated separately; and by their use direct communication has been had from Heart's Content, Newfoundland, to San Francisco. They are also often used for connecting branch lines with a main line. The first repeater was used for this purpose, and was designed and put into operation at Auburn, N. Y., to repeat press news from that office to Ithaca.

199. *What are the repeaters which up to the present time have been invented?*

The first was the one previously alluded to, and is universally known as the button-repeater. It was planned by Merritt L. Wood in September, 1846. The ext was the open-circuit repeater of Charles S. Bulk- , devised in 1848, which enabled messages to be sent between New York and New Orleans Farmer and Woodman in 1856 invented the first automatic closed circuit repeater, while after this in rapid succession came the automatic repeaters of Hicks—who has invented no fewer than three different forms of repeaters—Clark, Milliken, Toye, Gray, Haskins, Bunnell, and Gerritt Smith. The last one produced was that of Catlin. All of these have their special virtues, and have each been more or less used, but only a few of them are now in operation.

200. *State which repeaters are now most frequently used.*

Wood's button-repeater, though the oldest, is still much used on account of its simplicity and the readiness with which it is constructed by amateurs or in offices without special facilities. It is simply a switch which is capable of being placed in either of three positions. In one of these positions each line is connected, through a ground-switch, with a common ground-wire. In a second position the armature-lever of each of the sounders is interposed in the circuit of the other line so as to operate as an electro-magnetic key. The third position is but the second reversed. It needs an attendant all the time, as it can only be worked from one direction. When the receiving operator wishes to break he opens his key or makes dots, and the attendant, seeing that the sounders are not working together, turns the button, permitting the receiver to become in his turn the sender. When it is desired to work the two lines through as one it is only necessary to throw off the ground-switch.

The connections are clearly shown in Figure 82. M, M′ are the relays of the two circuits, S S′ their sounders, B and B′ the main batteries, 4 the ground-switch, E and W the east and west line-wires. When the lever, L, is in the position shown the wires are arranged as two independent circuits. To make a continuous through circuit the lever, L, is left untouched, but the ground switch, 4, is thrown off. To arrange the two circuits for repeating, the ground-switch, 4, is closed, and the lever, *L*, placed either on the plates 2 2 or 3 3. In the former position the eastern line repeats into the western, and in the latter position the western repeats into the eastern circuit.

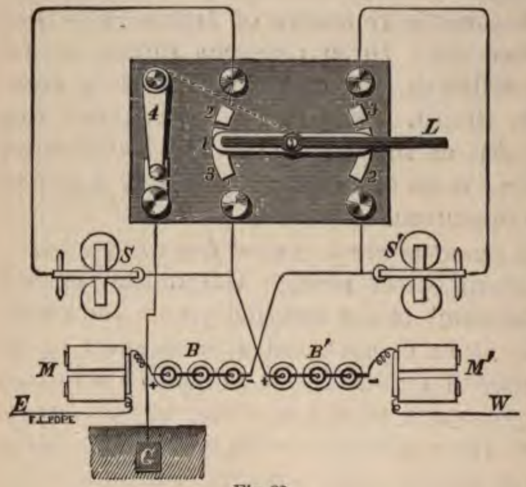

Fig. 82.

The automatic repeaters which are now most generally used are those of Milliken, Toye, Bunnell, and Haskins. The chief aim of all of them is to give the power of breaking, sending, and receiving to each circuit alike, and the great difficulty in the way has been to keep the armature of the relay of the receiving wire quiescent, and at the same time have it so arranged that it would promptly come into action when a break was made. This has, however, been successfully accomplished in many ways.*

An operator sending through a repeater must send firmly and heavily, and make long dots and correspondingly long dashes, because the lever of the repeating instrument requires an appreciable amount of time to make its stroke, and each repeater on a single line of communication shortens the current still more. For this reason the repeater-levers must be adjusted to as short a stroke as possible.

201. *Was there not a very simple repeater devised by Edison?*

Yes. It is described in Pope's "Modern Practice of the Electric Telegraph," and also in the "Hand-book of Diagrams and Connections" already referred to, and is shown in diagram by Figure 83. It is a very convenient button-repeater, has been found serviceable, and can be fitted up very quickly, as it needs no apparatus except the regular relays and sounders and a common two-point ground-switch. To set it up, the line, say from the west, is connected first with its own relay, M; thence it passes to the point 3 of the ground-switch, and through the local points of the opposite relay to the main battery, E, and ground, G. The other line is similarly connected; the main post of the ground-switch, S, is then connected with one pole of the local battery, E′. The other pole of the local battery connects with the sounder, L, passing from the second binding-screw of the sounder to the wire 1, which connects the two sets of relay-points with the ground. The sounder and local battery form a portion of both local and main circuits. When the button-switch is turned on to the point which touches the eastern circuit the eastern circuit repeats into the western, while the western relay works the sounder, and *vice versa.*

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* A full description of nearly all the repeaters that are, or have been, in use can be found in Davis and Rae's invaluable "Hand-book of Diagrams 1 Connections."

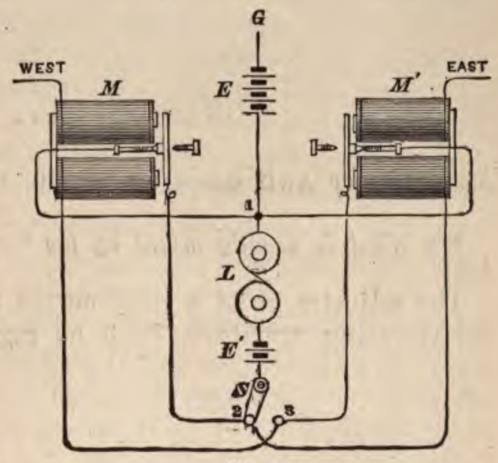

Fig. 83.

CHAPTER XV.

ADJUSTMENT AND CARE OF TELEGRAPH INSTRUMENTS.

202. *What is usually meant by the "adjustment" of a relay?*

The adjustment of a relay means the adjustment of its vibrating armature, both as regards its distance from the magnet-cores and the space through which it vibrates, or the length of its vibration. The first adjustment is regulated by the screw working the retracting spring of the armature, by the screw working the advance or withdrawal of the magnet, and by the front limit-screw, which also forms the contact-point of the local circuit. The latter adjustment is made by the two limit or set screws, between which the lever plays.

Ordinarily a relay should work well when adjusted as follows: With key open, or instruments cut out, fix the front limit-screw so that a moderately thick piece of letter-paper can be inserted between the armature and magnet-cores. Then screw up the back limit-screw till it is as close as possible, leaving an almost imperceptible movement to the lever. Then screw up the magnet until it is less than a sixteenth of an inch, place the instrument in circuit, and turn up the retracting spring. If the armature now sticks to the magnets turn up the spring still more; and if, when it is turned up pretty high, the action of the magnet is still too strong, the magnet must be withdrawn a little. We have seen operators who uniformly work with a slack retracting spring and magnet turned away back; but this is against common sense, for, to get the full benefit of the line current and to make the relay work quick and sharp, it is obvious that the magnet should be as close to the armature as it can be without sticking, so that it may advance sharply when the circuit is closed; and also that the spring should be adjusted high, so that the armature shall fall back promptly when the circuit is broken. Correct adjustment is one of the never-failing signs of a good operator, and it often, especially in wet weather and on way wires, demands great skill and attention.

203. *Why is it that the adjustment of the relay is very difficult on some lines in wet weather?*

Because in wet weather the escape of current from the line at each insulator (which even in the best-insulated lines is always present in some slight degree) is greatly increased and varies frequently, rendering the magnetism of the relay correspondingly uneven, being now stronger and again weaker.

This is especially the case in lines where the insulation is defective to commence with, and on some long way circuits it has often occurred that during a rainstorm it has been totally impossible to work the wire at all, or only in sections of a few miles in length.

The condition of the telegraph lines of America has been so much improved during the last ten years that such cases have now happily become rare.

204. *Why is it that during wet weather on badly working wires the relay often remains still when a distant station is sending, and why is it necessary to adjust high in order to get such stations?*

This is chiefly noticed on lines where the battery is divided, part of it being at one end and part at the other. As most of them are so arranged, it is a very frequent occurrence on lines of any great length. It is caused by the escape from the insulators which are between the station working and the station where the relay fails to respond. This becomes so considerable, by the aid of the wet insulators and poles, as to act the same as if an average country ground-wire were put on; and the current from the nearer main battery (if both batteries are equal in size) now has a circuit from the ground at the terminal station where it is located, over the line through the relays which remain still, to the escape arising from the united effect of leakage at a great many insulators at once; and the current in this artificial circuit produces sufficient magnetism in the relays to hold the armatures forward when the adjusting spring is at its usual tension, even when the current from the more distant battery is interrupted and the line opened by the key which is being worked at the distant station. This phenomenon can occur in either direction when a battery is placed at both ends, but only in one direction when the battery is at but one end of the line; for it is obvious that if a circuit have a battery at only one end, any office, by opening a key, cuts off the current from the entire line beyond it, and the armatures of all the relays beyond must, in consequence, fall back. Sometimes, therefore, in hard-working lines, where there is much escape during a rain-storm, the battery is taken off one end. When a relay, at its ordinary adjustment, refuses to respond to the signalling of a distant station, the spring must be adjusted higher, so as to put a greater strain on the armature, in order that it may overcome the attraction of the magnetism due to the escape. It will then respond to the breaks of the distant station. If the escape be still felt the magnet must be withdrawn a little by the back screw.

205. *What is the best method of adjusting on a hard-working line in wet weather?*

The best general way to adjust, both in wet and dry weather, is the common-sense method, which is as follows:

The limit set-screws should be so adjusted that when the armature is attracted it will almost touch the magnet-core, allowing just space enough to insert a piece of stout writing-paper between. This done, adjust the back limit-screw up so close as to allow of the least possible motion necessary to open the local circuit.

Screw up the back adjustment till the magnet is quite close to the armature; still, however, being careful that they do not touch. This is so that all the current on the line may be utilized on the magnet. Then screw the adjusting spring up till the tension is quite strong, thus giving the armature all the chance possible to fall back every time the main circuit is opened. If breaks still do not show clear on the sounder or register, the magnet must now be screwed back a little.

We may suppose the relay to be adjusted to be located at a station fifty miles from one terminal or repeating office and two hundred miles from the other.

In such a case it is probable that the greater part of the business will be to and from the former; and the best plan will be to keep the instrument so adjusted that the sending of the near repeating office comes light yet perfectly distinguishable. The call from that office, and all between it and the receiving station, may then be readily heard, while the heavy sending of the other terminal station and other distant stations have also a good chance to be heard. In any case, however, before opening the key in bad weather the adjustment should be pulled up, so that, if any distant station is using the line, its sending may be made manifest as the tension of the spring is increased.

206. *Why does a key sometimes stick, and what should be done to remedy a sticking key?*

When a key, on rising, does not break the circuit it is said to "stick." This sticking is generally caused by its platinum contacts becoming gradually burned and made rough by the repeated action of the spark which appears every time the circuit is broken, or by very small specks of metallic dust, which collect round the anvil and points. Sometimes it is occasioned by spongy or soft platinum having been used as the material for the contacts. This fuses to a certain degree every time the key is opened. In either case a partial and imperfect connection is produced between the two parts of the key, which should be completely insulated from one another when the key is opened.

When sticking occurs it can usually be remedied by rubbing the points with fine emery-paper. If that does not cure it a fine file may be very carefully employed, but only until a new surface is made. Frequent use of the file should, however, be avoided.

An inexperienced operator is often liable to mistake other troubles for a sticking key.

Dirty relay-points will, for example, so far as the register or sounder is concerned, act in precisely the same manner, and must also be cleaned with fine emery or sand paper.

Loose pivot-screws will often make trouble with a key, and should not be tolerated; the pivot-screws should always be kept as tight as is consistent with a free and easy movement of the key.

If a key has soft or spongy points there is no radical cure until the points are renewed.

In such a case the only way to make the key work at all is to give the lever considerable play when working it, and to clean the points frequently.

Keys with soft points are now happily rare.

207. *What precautions are necessary to get good work from a sounder?*

First and foremost, the sounder magnet helix should have about the same resistance as the local battery. If the battery consists of two cells of the gravity form, the sounder coils should have a resistance of about four ohms.

The sounder has three adjustments: one by which the play of the armature-lever is regulated, one by which the distance of the armature from the magnet-cores is regulated, and one determining the degree of tension of the retracting spring.

To adjust a sounder the armature-lever is first made to work easily and yet snugly upon its pivots, which are then locked by their set-nuts. Then the armature is fixed by the screw so that a piece of thick writing-paper can be passed between the core and the armature.

The screw regulating the stroke is then brought to a suitable distance to give the proper length of stroke, after which the retracting spring is screwed up, so that when the circuit opens the lever is pulled sharply back against its back limit-screw. If it now sticks when working, the spring must be tightened; if the spring is already tight the front limit-screw may be screwed up a little, thus bringing the armature to a point further from the core.

When a sounder gives a satisfactory sound it should be let alone.

A sounder should always be screwed down to the table, which then forms a sounding-board.

If a sounder has always worked well, but at length commences to stick, the adjustments should all be inspected to see if they are tight; if they are, the defect is probably due to residual magnetism in the cores, which may be measurably rectified by reversing the wires.

Care must be taken not to break or bend the fine magnet-wires in cleaning or dusting the instrument.

208. *How should a register be managed?*

The adjustments already described as belonging to the sounder are all of them in the register also. Besides these we find others—viz., that by which the rollers which draw the paper along are regulated, and the adjustment of the stylus, or pen.

The length of stroke, distance from cores, and tension of retracting spring are adjusted exactly in the same way as in the sounder.

To fix the pen-point correctly, first adjust the armature, screwing it to the proper distance from the core, then hold it there by closing the local circuit, at the same time letting the register run, and screw up the pen-point until it makes a mark on the paper which is plainly seen, then tighten up the set-nut.

The mark should only be deep enough to be distinct. The limit-screw regulating the stroke must allow the pen to just clear the paper when the circuit opens. If the paper runs crooked one end of the rollers presses tighter than the other, and the end that carries the paper fastest must be unscrewed a little. When the armature clips or sticks the relay needs adjusting.

The lever should never be allowed to work loose in its pivots, as that would cause irregular dashes, sometimes too deep, and at other times not deep enough. The paper guides must be just wide enough to allow the paper to pass through easily. If the register-lever does not respond to the movements of the relay there is some defect in the local circuit—very likely a loose connection, a weak battery, or dirty relay-points.

A register should be kept clean, but never taken to pieces out of curiosity; ninety-nine troubles out of a hundred met with by young operators are due to unnecessary tinkering with the instruments.

209. *When and how should a ground-wire at a way-station be used?*

A ground-wire should be used on a telegraph line only when the circuit is found to be open. It should then be used first as a testing wire, to ascertain on which side the line is open, and afterward put on, and left on, at the side of the instruments on which the trouble is found to be. When used as a testing ground it must be touched to both of the leading-in wires. If when touching either side it causes the relay to attract its armature, that is the side on which the trouble is, and that is the side on which it must be temporarily left; thus cutting that station in on the unbroken fragment of the line to the terminal station.

When the line is in working order the ground-wire should be left untouched. It is too much the practice among operators at way-offices to put on the ground-wire for any or no cause, but it is a habit that cannot be too strongly reprehended.

210. *Give some hints on the general care of a way telegraph station.*

Operators at way telegraph stations are frequently young and inexperienced. A few general hints may, therefore, not be out of place here.

After lightning-storms the arrester should always be examined to see if any damage to it has ensued. If so it should be fixed at once. If that kind of lightning-arrester is used in which a thin sheet of paper separates the ground from the line plate, the paper ought to be renewed, whether damage is apparent or not.

In bad weather the relay-spring should always be pulled up before the key is opened, to ascertain whether any one is using the line.

The motion of the relay armature-lever should be kept as small as possible, and the local points of the relay kept clean. The armatures, both of the relay and sounder, or register, must never be suffered to touch the cores of the magnet.

Every binding-screw about the office ought to be tried occasionally to see if it is tight, as the good working of the entire line often depends on this. Every loose connection introduces a high resistance into the circuit of which it forms a part.

When the instruments are working satisfactorily they should be left strictly untouched.

If the instrument table be covered with an oil-cloth, a space should in all cases be cut clear for the key, so that the latter will rest on the table. Many escapes have been traced to an oil-cloth table-cover.

All pivots should be just tight enough to prevent lateral play. This applies both to keys and sounders, or registers.

If an ordinary Daniell battery with porous cups be used for a local, it should be cleaned at least once a month. The zinc should not be allowed to touch the bottom of the porous cup. In cleaning such a battery, half of the clear liquid may be poured from the porous cup, and, after the cup is emptied and cleaned, poured back to form the zinc solution. If all the liquid is emptied it will be some time before the battery works up to its full strength again.

If a gravity battery be used the cleaning does not need to be nearly so frequent.

CHAPTER XVI.

CIRCUIT FAULTS AND THEIR LOCALIZATION.

211. *What are the faults most likely to occur on a Morse telegraph line, and how are they most frequently caused?*

Open wire or complete disconnection, partial or occasional disconnection, dead earth, swinging or occasional earth, escapes, crosses, swinging crosses, weather-crosses, and defective ground at the terminals.

Complete disconnection, familiarly called a "break," occurs when the circuit is open at any point, and till repaired puts an entire stop to communication. It may be caused in a variety of ways. The terminal ground-wire may be broken or cut, the battery may be defective, a key may be, and often is, left open, the line-wire may be broken—this may occur in many ways—or a wire may be accidentally pulled out of a binding-post in a station.

Partial disconnection occurs when the resistance of a circuit is greatly increased, and is also caused in a variety of ways. A rusty or otherwise bad joint on the line-wire, a wire loose in a screw-post, an imperfect terminal ground-wire, or a very bad main battery will cause this trouble; and it manifests itself by causing the instruments in circuit to work in a feeble and irregular manner.

Dead earth, in American phraseology, is called a "ground." It occurs when the line at any point touches the earth, or some good conductor in contact with the earth. When the resistance of such a fault is very low indeed it practically divides the line in two parts, each terminal station working on its own battery to the fault.

If only one station has a main battery the relays between that station and the fault will work stronger than usual, because the total resistance of the circuit is decreased; while the instruments beyond the fault will be apparently out of circuit, and will act as if the line were open. If there is a battery at both ends the stations on each side of the ground will be able to work, but those on one side will be unable to communicate with those on the other. This trouble may be caused by contact with a wire running to earth, or by the line-wire lying across a tree or roof; but is oftenest caused by operators in way-offices, who attach a ground-wire to the line for no sufficient reason, and forget to remove it.

A *swinging* or *occasional earth* is of the same character as the preceding fault, with the exception that instead of being a permanent interruption it comes on only at more or less regular intervals. It is a serious fault, and often difficult of localization, as such a ground frequently does not stay in long enough to enable it to be tested. It is usually caused by the line-wire swinging, under the influence of the wind, against some conducting substance in contact with the earth, such as a guy-wire.

An *escape* is also of the same general character as a ground. The difference is only one of degree; for while, in the case of a dead ground, nearly all the working current leaves the line at the fault, only a portion does so in the case of an escape. It is, in fact, simply a branch circuit of comparatively low resistance, by which a certain portion of the current of electricity escapes or leaks to the earth at the wrong place, thus weakening the line current beyond the fault, and strengthening it between the main battery and the fault. It is caused by defective insulation of the line, instruments, or battery, or by contact with an imperfect conductor, such, for example, as a tree.

A *cross* occurs when two wires come into contact, and is generally caused by the wind or by swaying branches of trees. When two wires are crossed a message sent on one is repeated on the other, so that neither one can be worked without interfering with the other. In such cases the means adopted is to open one wire on each side of the cross until the cross can be cleared.

A *swinging* or *intermittent cross* occurs where one or more wires are too slack between the poles or supports, so that they are often blown one against the other. This trouble is an annoying one, as it is very difficult to locate, for the same reason as that given in describing the intermittent ground. It is of frequent occurrence among the short house-top lines of cities.

A *weather-cross* sometimes occurs in wet weather from defective insulation. In such cases the moisture on the insulators and cross-arms enables the electricity to escape or leak from one wire to another. The evil effect of this trouble is much lessened by earth-wiring the poles.

Defective ground terminals act as if all the wires running to ground at the same place were crossed together. It is frequently caused by the severance of a gas-pipe which is used for the common earth connection. It is also sometimes caused by such a pipe being an imperfect conductor, or by the connection of the wire to the pipe being imperfectly made.

212. *How does a disconnection, or break, make itself apparent, and how is it to be tested for?*

If the line is broken at any point the armatures of all the relays at once fall back, and no work can be done until the line is repaired. If the trouble is caused by an open key the operator at that station will probably sooner or later discover it and close it. But if the line-wire is broken at any point a lineman will have to be sent out as soon as the trouble is located between two stations.

As soon as the circuit is discovered to be open the operator at each way-station should connect his ground-wire first with one side of the instrument and then with the other. If connecting it on either side closes the circuit it shows that the trouble is on that side, because on such connection the break is cut off and the line virtually terminated at the ground-wire, cutting the instruments in.

In Figure 84, which represents a line with four stations, A, B, C, and D, the wire is supposed to be broken at F. When B and C attach their ground-wires, as shown and described, it will be seen that two distinct circuits are formed: A then being able to work with B, and C with D. The fault is thus shown to be between B and C.

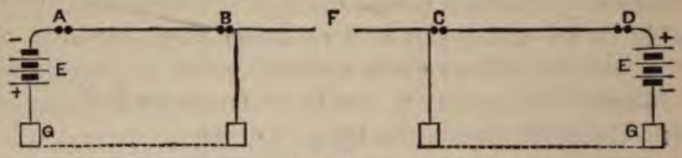

Fig. 84.

If the application of the ground-wire fails to close the circuit on either side, the trouble is either in the office, or the ground-wire that the operator is testing with is defective, or some other office has already closed the circuit by the connection of a ground-wire. Hence an operator should always, after testing with the ground-wire, make sure by a careful search that the trouble is not in his own office.

As soon as any office discovers on which side the line is open its duty is to report the facts to the remaining terminal station, and from it receive instructions whether or not to keep the ground-wire on. Failing such instructions, a good plan is, if there are many stations between the way and terminal station on the complete side, to keep the ground on and frequently remove it temporarily to see if the circuit has closed; but if the said way-station is near to the terminal station on the side which is unbroken, it is better to keep the ground off, because the greater number of stations are beyond; and when any one of the way-stations has a message to send it can then connect a ground-wire and send it.

A break is often tested for with a galvanometer, the general principle of such a test being the comparison of the known insulation resistance when the line is complete with the insulation resistance from the terminal stations to the broken ends. It is, of course, a matter of absolute necessity to test for a break in a submarine cable in this or in a similar manner.

213. *What method may be adopted on short city lines of special systems, such as American District or stock-printer lines?*

The quickest and most satisfactory way is to put on to the broken line a battery of sufficient strength, and then have an inspector or lineman go from station to station, grounding each instrument for an instant as he goes along, until he reaches an instrument which, when grounded on the side away from the office, does not work, or on which, if a light battery is used, he can taste nothing. He has then passed the break, and, retracing his steps to the last station, he there attaches a ground, leaving it connected until the break thus located between two stations can be repaired.

214. *What are the effects of an intermittent disconnection, and how may such a trouble be located?*

An intermittent disconnection is frequently by inspectors and linemen called a *swinging break*. It often occurs from a loose connection, a hook-joint which is alternately tightened and loosened by the wind, or, in the case of covered wire, it may be caused by the conductor being broken inside the covering. On ordinary lines it will occasionally make itself apparent by the sound of a dot on the sounder, and it sometimes proves very annoying to operators by opening the circuit for an instant while a message is being sent. On printing circuits it shows by the instruments missing a beat, and then "throwing out," causing the printed slip to write nonsense, while on District circuits and the like a long dash is produced on the register-tape and the bell rings.

The most satisfactory way, and the only method to be depended on, for the location of a trouble of this character, is to cross-connect the defective wire with another at an intermediate station. This method may be adopted on either long or short lines, and is as follows: It is better, for the sake of celerity, to make two cross-connections at once. For example, we will suppose two parallel lines, No. 1 and No. 2, both running into stations A, B, C, and D, and that No. 1 has an intermittent break. At the point where the wires leave station A interchange them so that No. 1 inside the office connects with No. 2 outside, and *vice versa*. Duplicate the change also at station C. No. 1 is then temporarily No. 1 from its initial ground at A to the window, No. 2 from there to the switch at station C, and again No. 1 from C to the terminal ground. No. 2 is, of course, correspondingly changed. Suppose now the fault is between B and C on No. 1; the trouble will be found to have moved over to No. 2 at the terminal stations A and D, because that portion of No. 1 in which the fault is located has by cross-connection been transferred to No. 2 circuit. When this is ascertained the wires at the distant station C may be straightened and the cross-connection changed to station B. Supposing still that the fault is between B and C, it will, the next time it comes in, be found to have changed back to No. 1, because that section of line has been transferred back again to No. 1. Now, when thus located between two stations, it can generally be easily found by a lineman. If it is, however, still troublesome, and cannot be found, the lineman will have to cross-connect between stations.

215. *How should a partial disconnection causing an extremely high resistance be tested for?*

The method of cross-connection described in the an- r immediately prior to this is the most satisfactory to pursue when only the ordinary telegraph instruments are at hand. If, however, a good galvanometer and rheostat can be readily obtained, a quicker way is to employ them, especially if the fault is constant. It will be of great assistance to the tester, in this operation, if the resistance of the line at ordinary times is known; but even if it is not it can usually be calculated. First measure the suspected line, and see what the resistance is with the fault in; then have a good ground put on about half way to the terminal, and measure again. If the high resistance is still in take off the ground and attach it nearer, and measure again; if, on the contrary, by grounding the first time the high resistance is taken out, the trouble is beyond, and the ground must be attached at a more distant point. By continuing the measurements the trouble can soon be localized between two stations.

216. *How should a ground or dead earth be tested for?*

The method in general use is to call up all the stations, one after another, and see what ones can be raised. If, for instance, a line has twenty stations and the most distant one that can be raised is the tenth, the presumption is that the ground is beyond that station. This is used where there is only one wire. If there are two or more wires the testing office can call the way-offices in rotation on No. 2 and direct them to open No. 1. So long as the opening is not perceptible at the testing station the ground is between the station opening the key and the testing station; but as soon as the opening of the key at a station is perceived at the testing station the ground is passed and is then beyond the station opening. If a galvanometer is used and the normal resistance of the line is known, the distance of the ground from the testing station can usually be calculated from the measured resistance with the fault in. A dead ground is very often caused by lightning burning out the paper between the plates or fusing the points of a lightning-arrester. On a very short line having many stations or instruments, such as a stock-printer line, the quickest plan to locate a ground is to go from station to station. The instruments on the battery side of the ground will be observed to work stronger than usual, while those beyond the ground will work much weaker or not at all.

217. *How does an escape manifest itself, and how is it to be tested for?*

An escape is manifested much in the same manner as a ground, but its effects are not so pronounced. Stations on different sides of an escape, under ordinary conditions have to adjust high to work with each other. It is sometimes found advisable to take off the battery from one end of the line, and let the magnetism in the relay at the receiving end be produced entirely by the influence of the battery of the sending end; because even though a portion of the current from that battery is lost at the escape, the portion which does arrive at the receiving station beyond the escape is necessarily affected by the key of the sender, since whenever that key is opened all the current is taken from the line. When this is done, however, the receiver must not break, as if he did it would not be noticed by the sender, the circuit being, in any event, partially completed by the escape.

Figure 85 represents a line with a main battery, E, at each terminal station, and a fault, consisting of an escape, F, between the two stations B and C; the terminal stations are indicated by the letters A and D.

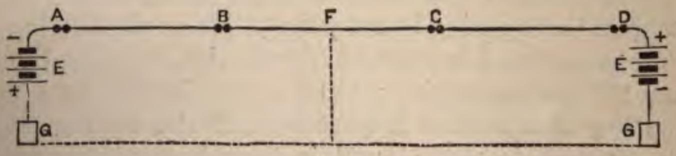

Fig. 85.

To test for this escape the stations of the faulty wire must be called up, one after another, either by means of a second wire or by the faulty wire itself, and told to open key for a minute or so. When the stations beyond the escape open a current will be still on the line from the testing station to the escape, and will affect the relay of the tester; but as soon as the first station on the testing-office side of the escape opens the current will cease and the tester's relay will fall back. Thus, in the figure, supposing A to be the testing station, when C opens key there is still a current on the line from the battery E through the escape to ground; but when B opens there is no current, showing the escape to be between B and C.

218. *How is a cross or contact between two wires to be localized?*

When a cross occurs between two wires it is obvious that the two wires will be reduced to one, if one of them is opened on both sides of the cross, or if one is opened on one side of the cross and the other on the other side of the cross. Therefore to test for a cross, say between two wires, No. 1 and No. 2, the most distant station that can be raised must be called up and instructed to open one wire—No. 1, for example—and make dots on the other. The testing office will open No. 2, and if the dots of the distant station come on No. 1 at the testing station the wires are obviously crossed. Now instruct the distant station to leave No. 1 open; then call up the next distant station, direct it to open No. 1 and send dots on No. 2, opening No. 2 at your own station. If the cross is still between the testing office and the distant station the dots will still come on No. 1; but if the cross is between the station now sending dots and the preceding one both wires will now be open at the testing station. The cross is thus readily located. The testing operator or circuit manager must call up and test with station after station in regular succession until the cross is located.

219. *How must an intermittent ground or cross be tested for?*

The only reliable way to test for and locate an intermittent ground is to cross-connect the faulty wire with a perfect one and wait until the next time the fault shows, observing then whether it is transferred to the second wire with the cross-connected section of line, the whole process being in every respect similar to that of testing for an intermittent disconnection described in question 214.

The same remarks apply generally to intermittent troubles of any character.

220. *How does a weather-cross affect telegraph lines, and how and when must it be tested for?*

A so-called weather-cross shows a similar effect on a line of telegraph to that caused by a cross, but in a much less degree. It must be tested for in the same way, and the testing must be done while the wet weather continues, as it is only then that such a fault is sufficiently apparent to be tested for.

221. *When a defective ground connection is suspected how may it be tested for and discovered?*

When such a fault is suspected it may often be found by searching, without testing at all. If it cannot be readily found or proved to exist by search, it can be tested for by several methods. The *first* is: If more than two lines run to the same earth, first take off all the lines except two, then open one of these two and put a considerable battery on the other. If the ground is very defective a large share of the current will leak past it and make itself manifest to the taste at the end of the opened wire. A *second* way is given by Haskins, [illegible] follows: "Connect a wire to the suspected [illegible] tween the battery terminal and ground, [illegible] no battery, to the ground-wire between [illegible] ent and the ground; connect the other [illegible] a galvanometer, connecting the other [illegible] vanometer to a good earth. If the [illegible] defective the current will divide where [illegible] attached and will go to ground through [illegible], deflecting the needle." Haskins also [illegible] ing method of measuring the resistance [illegible] ground: Measure any two lines to earth through the suspected wire, then disconnect the two wires from the ground, connect them in metallic circuit, and measure the loop so made. If the sum of the two resistances measured to ground exceed the resistance of the metallic loop, then the excess, divided by two, will give the resistance of the defective ground.

CHAPTER XVII.

MULTIPLE TELEGRAPHS.

222. *What is meant by the term multiple telegraph?*

The term embraces all the various methods of simultaneously sending two or more communications or messages, either in the same direction or in opposite directions, over a single line. It includes the duplex, quadruplex, the various multiplex methods which have been introduced or projected within the last ten years, and the harmonic systems of telegraphy, introduced by Varley, Gray, Lacour, and others.

223. *What is the duplex?*

It is simply an ordinary telegraph, so constructed and arranged that two communications may at the same time be transmitted intelligently over the same wire. Usage coil of the relay to the line to operate the relay at the distant station. A *differential relay* is one which is wound with two separate coils in different directions. The effect when a current is passed through it is that the current from the home battery is equal in both coils, and, they being wound in different and opposite directions, the magnetic effect caused by the current in one direction in the relay will be neutralized by the current in the other direction, and so the effect of the outgoing current will be nothing; but when the current in the coil leading to line is reinforced by a current from the distant station, it overbalances the current in the other coil and gives the signal. The only other popular and much-used system of duplex is what is known as the *bridge* duplex. In it the receiving instrument is placed in the cross-wire of a Wheatstone bridge, and the connections are arranged in accordance with that well-known principle. The success of both the differential and bridge duplexes is due to the improvements made by Mr. Joseph B. Stearns.

224. *Give a brief history of the duplex, naming its successive improvers and inventors.*

The first to broach the idea of using one wire for the simultaneous transmission of two messages was Mr. Moses G. Farmer about 1852. Dr. Gintl, director of the Austrian State Telegraphs, was, however, in 1853 inventor of a practical duplex system, which was the parent stem of the present differential systems. He used a differential relay, of which one coil was traversed by the line current, and the other by the current of a local equating battery of opposite polarity, the combined effect being to hold the armature of the home relay still, and thus subject to the action of the current coming from the distant station. It was very rudimentary, and was in rapid succession followed by the duplex systems and improvements of Frischen in 1854; Gintl, in a chemical duplex, which was practically operated in 1854 between Vienna and Linz; Nyström, of Sweden, in 1856, whose principal improvement was to maintain the connection between the line and earth always unbroken by means of a circuit-preserving key ; Mr. W. H. Preece, of England, in 1855 and 1856 ; Siemens and Halske's two-relay method ; Zur Nedden in 1855, and Farmer in 1858. All of these different improvements, however, fell flat, chiefly because the time for them had not arrived, and the science of telegraphy was not developed to such an extent as to require a satisfactory system of duplex telegraphy. Hence all these methods were looked upon merely as electrical curiosities. In 1863 the interest in this branch of telegraphy seemed to revive, and Maron, a Prussian telegraph inspector, effected another improvement by which the receiving instrument was placed where it would not be acted upon by outgoing currents. Frischen also, in 1863, improved his former method. In 1868 Mr. Joseph B. Stearns, of Boston, commenced a series of experiments with the duplex of Siemens and Halske, and was soon so successful that duplex telegraphy, which had now become a necessity, was roused from the torpor which had hitherto crippled it, and was rapidly brought into general use. He applied a transmitter in a local circuit instead of the old key, and caused it to make the contact of the battery with the line before the interruption of the contact between the line and the ground. He made this transmitter act also as a sounder, so that the American operator, accustomed to hear his own sending, could be thus accommodated. He subsequently connected a condenser to the rheostat, forming an artificial line, and thus balanced the static charge which came from the line when the line was changed from battery to ground. Mr. Stearns also introduced his transmitter and condenser into the bridge system, where the receiving instrument is placed in the cross-wire of a system of circuits and resistances, arranged at each station on the plan of the well-known Wheatstone bridge. The receiving instrument is thus placed beyond the range of electrical impulses originating at its own station, while free to respond to those caused by the distant station. This is widely used and known universally as the bridge duplex. The success of Mr. Stearns spurred up many inventors, and duplex telegraphs, each having features more or less meritorious, were brought out by the following well-known electricians: Gerritt Smith; Vaes, of Rotterdam; G. K. Winter, of India; George D'Infreville, J. C. Wilson, C. H. Haskins, T. A. Edison, and others. Duplex telegraphs are still being produced, although the quadruplex has greatly diminished their importance.

225. *Give a short description of the entire principle of the Stearns differential duplex.*

The differential relay, as heretofore explained, is a relay the magnets of which are wound with two separate wires of equal length and size, and consequently of equal resistance. Such a relay is employed; and the wire from the main battery, which is controlled by the transmitter, is connected with the leading-in wire of one coil, and with the leading-out wire of the other coil, so that when by the action of the transmitter the battery is thrown on to the main wire of the relay, the current circulates round the soft-iron core in both directions at once, and the magnetic result in the core is consequently nothing, so long as the home current only is employed. One of the wires leading from this relay is now connected to the line-wire, and the outer end of the other is connected to a rheostat or resistance-coil of approximately the same resistance as the line. It will be observed, therefore, that the respective differential circuits of the relay are both extended, the one through a long line to earth, the other through a resistance to earth. It was one of the old difficulties that when the contact of the line to earth was interrupted a momentary break occurred before contact with the battery was made; Mr. Stearns so arranged his transmitter that the contact of the battery was made before that of the line with the earth was broken, much as Nyström had done in 1856.

The transmitter is operated by a local circuit and an ordinary Morse key, and its entire office is to alternately put the line to battery and ground.*

It was found that when the battery was connected to the line, the line became statically charged, and when it was put to earth this charge returned through the relay, causing it to give a "kick." Stearns saw that all the conditions of a line of telegraph were not fulfilled by his balancing resistance-coil, and he accordingly devised the attachment of a condenser around the rheostat or resistance-coil which formed the artificial or balancing line. This added the missing feature, electro-static capacity, with the result that when the line was charged the condenser connected to the artificial line was also charged, and when the line discharged through one wire of the relay the condenser discharged through the opposite wire, thus balancing the forces and neutralizing the "kick."

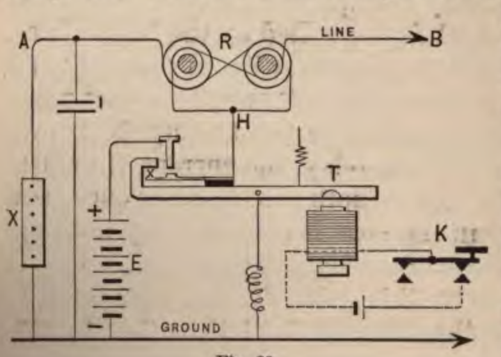

Fig. 86.

Figure 86 is a theoretical diagram of one station, arranged for duplex transmission, with the local connections omitted. T is the transmitter, operated by a local battery and key, K, and connecting with the relay, R; this is wound differentially, the wire leading from the transmitter dividing at the point H, one division traversing the relay in one direction and leading to line B, and the other passing through the relay in the opposite direction, and through a wire, A, and rheostat, X, to ground. The transmitter is also grounded by a wire extending from its lever to the ground-wire. The condenser, I, is shown connected as a shunt to the rheostat, and is united on one side to the wire A at a point between the relay and rheostat, and on the other side to earth.

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* The invention of the transmitter is now ascribed to Farmer.

The differential relay, being, as we have described, irresponsive to the impulses of the transmitter at its own station, yields readily to those sent from the distant station, because the currents passing through the line-coil of the relay are reinforced by the current coming from the distant point, and thereby predominate over that part of the current which passes through the artificial line; magnetism in the relay-core ensues, and the signals are produced.

226. *Give a general description of the bridge duplex.*

The bridge duplex is simply an arrangement of circuits, in which the receiving relay is placed in the cross-wire of a Wheatstone bridge or balance. It is well known that the Wheatstone bridge is usually represented by a diamond-shaped parallelogram, with two of the opposite corners connected respectively to the two opposite poles of a battery; the other two opposite corners being connected by a cross-wire having a galvanometer in circuit. In such an arrangement of circuits no current passes through the cross-wire, provided the resistances of the opposite circuits on each side are either equal, or are in the same ratio, one to the other. It is, of course, immaterial what form the arrangement of the circuits really is in, if the connections are substantially as indicated here.

The foregoing principle is utilized in the bridge duplex. Figure 87 shows in diagram the theoretical arrangement of the bridge duplex. The battery is connected through the transmitter, K (which in practice is similar to that of the differential duplex), to the point, H, where the circuits diverge to form the arms of the bridge; between this point and the cross-wire, on each side, are placed adjustable resistances, A and B, thus forming the first two arms of the bridge; the line L to the distant station, and there to earth, is the third arm, while a rheostat, R, looped by a condenser, C, is the fourth arm. The relay, M, is placed in the cross or bridge wire. V and W are small resistances placed in the circuit to prevent any short-circuiting of the battery, and also to avoid variation of resistance when the line is changed from battery to ground, or *vice versa.*

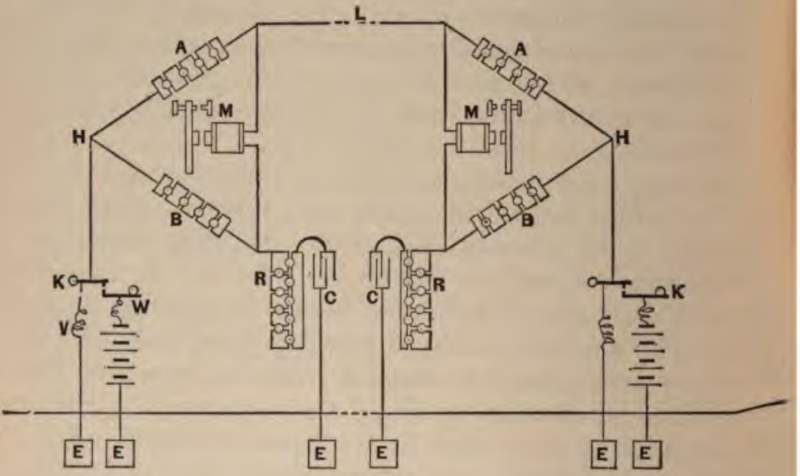

Fig. 87.

The four resistances are adjusted to a suitable ratio, so that the relay does not respond at all to the outgoing current, while it must respond to the incoming current, since a certain portion of that current must necessarily pass through it to earth. The condenser in this system is adopted for the same reason as in the differential system—namely, to counteract the effect of the electro-static discharge from the line by a similar one in the opposite direction from the condenser.

The great advantage of the bridge is that it can be readily used with any character of apparatus, from a relay to a Thomson galvanometer. It is also less likely to suffer injury from lightning than is the differential.

Ordinarily for long circuits the differential is to be preferred, because with a given amount of battery a stronger working current and a greater magnetic force is developed in the receiving instrument.

227. *What has been done towards duplicate transmission in the same direction?*

The first attempts in this direction were made in 1855 by Dr. J. B. Stark, of Vienna, and by Siemens, of Germany; these were shortly after succeeded by Kramer, and subsequently by several others. None of these systems was ever brought to practical application, although all were most ingenious and beautiful.

A description of the method of Stark will suffice, as showing the general tendency of all. Two keys are, of course, required at the sending station, and two receiving relays at the receiving station. Four conditions are therefore to be provided for—namely, 1st, when No. 1 key is closed and the other open; 2d, both keys closed; 3d, No. 2 key open and No. 1 closed; and, 4th, both keys open. Dr. Stark accomplished this by sending with key No. 1 a comparatively weak current, and with No. 2 key a stronger current, while when both keys were closed the combined currents were sent; finally, when both keys were open no current was on the line. He arranged at the receiving station two relays, so constructed that when the weaker current was sent one relay would respond, and when the key sending the stronger current was depressed the other relay would respond; while when both keys were operated both relays would respond. This was effected by adjusting the relay working with the strong current with a retracting spring of high tension, so that its armature would not move with the weaker current. When, however, the other key was depressed, the armature of the relay moved, and not only closed the circuit of its own register or sounder, but also closed the circuit of another or auxiliary battery, causing a current to circulate round the coils of the first relay which is differential but in an opposite direction to that of the line current; the armature of that relay is thus held quiescent. When both keys are operated the current passing through the coils of the first relay, or that responding to the weak current, is strong enough to overcome the local current in its other coil, and it also responds.

Serious difficulties developed themselves in this system, as in others of the same class; and not until the practical introduction of the Stearns improvements on the duplex was this idea made thoroughly practical.

228. *What is the quadruplex?*

The quadruplex is the name given to the apparatus and method whereby four messages may be transmitted upon one wire simultaneously, two in one direction and two in the other.

229. *How far back does the idea of a quadruplex date, and to whom is its first conception due?*

It dates back to 1855, when Stark, while experimenting on the problem of double transmission in the same direction, saw that upon the successful solution of that problem depended that of the greater problem of quadruplex telegraphy. His description of his proposed method of simultaneous transmission in the same direction concludes with the following memorable words: "With the method of double transmission in the same direction we may also combine that of counter or opposite transmission; and hence arises the possibility of simultaneously exchanging four messages upon one wire between two stations, which will, however, hardly find any application in practice." Dr. J. Bosscha, Jr., of Leyden, also, about the same time foresaw the ultimate result of a successful system of double transmission in the same direction, and in a paper read before the Royal Academy of Sciences in Holland, in 1855, after describing his own method for the accomplishment of that feat, he proceeded to outline a method of achieving the greater result. He simply proposed to add to his own system the duplex of Siemens and Halske, or of Frischen. It is very evident, therefore, that both of these inventors recognized the fact that quadruplex telegraphy depended entirely upon a successful system for double transmission in the same direction.

230. *What is the origin and principle of the American quadruplex?*

It originated in experiments made in 1874 by Thomas A. Edison, in association with George B. Prescott, with a view of improving the Stearns duplex. While engaged in this work Mr. Edison devised a new method of double transmission in the same direction, which was more practical than any of its predecessors, and at the same time differed essentially from them. His method was, like the discovery of America, simple enough when known, and consisted in combining the system of telegraphy known as the double-current system, wherein the telegraphic signals are transmitted by rapidly reversing the poles of a battery which is always kept on the line, so that the current is constantly alternating in direction from positive to negative, and *vice versa*, with the single-current system, wherein transmission is accomplished by breaking and closing of the circuit, but in this case the current is simply made to increase and decrease. Thus two distinct qualities of electricity, direction or polarity, and strength, are utilized, and an entirely new method of double transmission in the same direction was the result. As foreseen by Stark and Bosscha, it was now an easy matter to apply to this new method the Stearns duplex, or indeed any other practical duplex; which was accordingly done, giving to the world the far-famed quadruplex.

It was ascertained by practical experiment that the bridge duplex was better adapted to the conditions necessary for success than the differential, and the bridge was therefore employed with the earlier combined systems. In practice two transmitting instruments were set up at each end of the line, both worked by an ordinary Morse key, opening and closing a local battery circuit. One transmitter, the one nearer to the line, operated simply as a pole-changer without regard to the strength of battery used. The other operated, when depressed, to add to the ordinary battery about three times as many cells as it would usually have, so as to increase the strength of current correspondingly, irrespective of the polarity. A certain amount of battery was to be always in circuit. These transmitters were placed in the circuit of the wire leading from the battery to the bridge. In the cross-wire of the bridge, at each end of the line, were placed two relays: one a polarized relay, responding only to the sending of transmitter No. 1 at the opposite end, or the pole-changer; and the other a relay with a neutral or non-magnetic armature, which responded only to the sending of the transmitter No. 2, which increased or decreased the battery. By the use of this apparatus it was made possible to send two messages from each terminal station at the same time, and consequently to receive at both stations an equal number. An old annoyance, however, showed itself here. The moment of change of polarity, when the polarized relay was being operated, would affect the neutral relay, causing it, if occurring at the same time that the neutral armature was attracted, to make a false break. To remedy this defect Edison caused the armature-lever of his neutral relay to make contact on its back limit-stop, closing a local circuit which included an electro-magnet. This electro-magnet in turn closes the sounder circuit by making contact on its back stop. By thus interposing a local circuit the interval of non-magnetism was made too brief to affect the sounder. He also incorporated an additional electro-magnet and a condenser, looping a rheostat placed in the bridge-wire, to overcome the effects of the static discharge upon the neutral relay. These devices were, however, cumbersome, and not always effectual, and, though the quadruplex was at this time a tolerable success, it left much room for improvement by subsequent inventors.

231. *What changes and improvements have been made in the quadruplex since its introduction?*

The changes in the working arrangement of the quadruplex have been numerous and important; and although many of them have been the result of careful and painstaking thought and exhaustive experiment, curiously enough, at the present time, after a fair trial of the numerous modifications, the entire system in its essential features is much the same as when first made public.

The improvements referred to were, of course, made with a view of simplifying the apparatus and arrangement, and of obviating certain faults which had showed themselves. In place of the bridge it was found possible to substitute the differential-circuit arrangement. A compact double-current transmitter was devised, and certain receiving instruments were brought into use, which, while comprising features of great novelty and ingenuity, unfortunately introduced the element of complication. The new double-current transmitters have been made extremely simple, and yet capable of the most accurate adjustments, so that the current of one polarity does not cease till that of the opposite polarity commences to flow, while at the same time the time that the battery is placed on short circuit is reduced to an infinitesimal period.

The receiving relays were, as already indicated, somewhat complicated, a polarized relay replacing the neutral relay of Edison. This was so arranged with contact-levers that at all times when the entire force of the batteries was on the line its local circuit was opened, because the armature was either drawn to its full extent in one direction or the other, in either case opening the local circuit. When, however, the battery current on the line was decreased or withdrawn by the depression of the proper key, the armature, not being so forcibly attracted, would stay in the centre, being held there by its contact-levers, at the same time closing the sounder circuit. The other relay was, of course, also polarized, and responded to the movements of the double-current transmitter only, closing its local sounder circuit only when its armature was drawn to one particular side by a current of definite direction, whether that current be strong or weak. Thus both relays were by this plan polarized, one closing its local circuit when drawn to one side and opening it when drawn to the other side, and the other closing its circuit only when a weak current was on the line, and breaking it the moment a strong current was transmitted. The principal defect in the original quadruplex—namely, that of allowing the neutral relay to make a false break at the moment when the direction of the current changed—was thus overcome. Subsequently it was ascertained that a small neutral relay with short cores was capable of being reversed with sufficient rapidity to answer every requirement, and such a relay was then made to replace the double-tongued polarized relay, thus bringing the quadruplex back almost to its original form.

The usual arrangement of the quadruplex as now operated includes the neutral relay, and has a condenser between the main and artificial line. The differential system is also preserved.

In New York dynamo-electric currents are used; and in conjunction with them it has been found necessary to employ an entirely novel key system, the ordinary quadruplex key system not being suitable.

Probably the longest circuit in the world working quadruplex all the way through is that between New York and North Sydney, C. B., via Worcester, Portland, and Bangor; a repeater being in circuit at the latter place, the entire distance being about twelve hundred miles, and the line built of No. 4 galvanized iron wire.

232. *What is the electro-harmonic system of telegraphy?*

It is a telegraphic system based upon the facts that ical tones produced by the vibration of an electrotome or circuit-breaker may be transmitted through a telegraphic circuit, and reproduced at the other end of the line in tones of like pitch, by the vibrations of suitable armatures; and that by employing a set of circuit interrupters or changers, each acting by rapid vibration to produce a distinct musical tone of a pitch different from the others, and transmitting the said tones, successively or simultaneously, over a single circuit common to all the circuit-breakers, and through a series of electro-magnets fitted, instead of armatures, with steel ribbons rigidly fixed at one end and provided with turning-screws at the other, so as to give them the proper tension, each of these ribbons being tuned to give out the same note as its corresponding circuit-interrupters, each receiver will analyze the tones transmitted through it, pick out its own, and allow the others to pass without interference or interruption to their respective receivers.

The method of applying this system to telegraphy is well explained in an article prepared under the supervision of Mr. Gray (who has been the chief inventor in this application of electricity) for the New York *Review of the Telegraph and Telephone*, and also in a lecture delivered before the New York Electrical Society, April 6, 1883, and subsequently published in the New York *Operator*.

The following description is chiefly drawn from these sources:

A battery, P_1, P_2, P_3, P_4, Figure 88, united on one side to the ground, sends in line L an electric current which, at the receiving station, crosses seriatim a certain number of electro-magnets—four, for example, E_1, E_2, E_3, E_4. Before these latter are placed the reeds B_1, B_2, B_3, B_4, and, under the influence of the variations of the intensity of the current, each electro-magnet puts in vibration, like the diaphragm of the telephone, a corresponding reed. Further, the four reeds, fixed permanently at one of their extremities, are regulated in such a way as to give in vibrating four entirely distinct tones; consequently each of them is only affected by the vibrations of the current when these variations are in accord with the number of vibrations which correspond to it.

On the other side the battery of the sender is divided into four groups, and upon each of these groups is disposed a derived circuit, including a vibrating reed and a key for making and breaking the contact. There are thus four vibrating reeds, vibrators V_1, V_2, V_3, V_4, and four contacts, C_1, C_2, C_3, C_4. Each time that one of the vibrators touches its contact the circuit from the corresponding battery is shut off and the current is diminished; when the circuit is again cut on the current resumes its first intensity, but the vibrators set in action, each by a special magneto-electric system, are constantly driven by a determinate vibratory movement, and the number of vibrations of each of them is the same as that of one of the reeds of the receiving apparatus; that is to say, that V_1 will have a number of vibrations equal to that of the tone which gives B_1, V_2 the number of vibrations corresponding to the tones of B_2, etc. Each vibra-

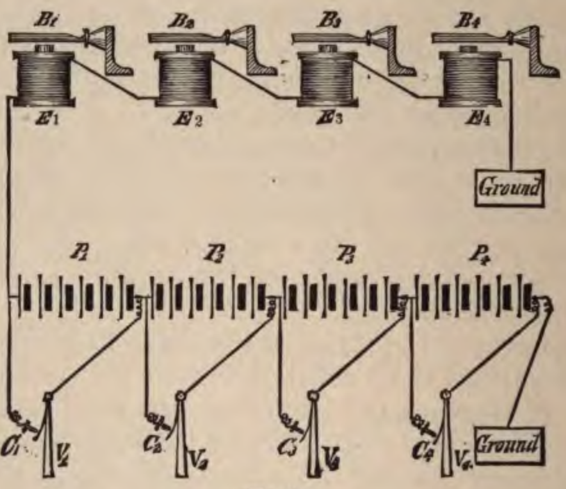

Fig. 88.

tor will determine then in the current very rapid vibrations, and will produce a series of electric waves in relation with the number of vibrations which it effects. All the vibrators being in action at the same time, there will pass, consequently, in the line four series of distinct electric waves; and each of these series of waves finding at the receiving station a reed in harmony with it, under its influence all the reeds, B_1, B_2, B_3, and B_4, will enter into vibrations.

If now one of the vibrators is stopped the series of electric waves which correspond with it would be suppressed, and the corresponding reed ceases to vibrate. If two. three, or four of the vibrators are stopped the arrest of two, three, or four of the reeds will be effected. These arrests will be heard at the receiving station; and, by making short and long stops, a sort of Morse alphabet can be arranged to transmit simultaneously four different despatches.

What we have said represents, in short, the harmonic system of transmission invented by Mr. Gray; but it is evident that in practice special arrangements must necessarily be taken to assure good results. We wish now to indicate these arrangements, after having described in detail the different apparatus employed.

We will describe, in the first place, the receiving apparatus, and will indicate how, in the place of producing signals by means of stops in the sound of the receivers, these stops are transformed into electric contacts susceptible of producing ordinary electrical signals.

The receiver, with its local sounder, battery, and connections, is represented in Figure 89. To the left of the vibrating end of the reed is a supporting piece holding a small bent lever, called a rider, which is nearly balanced at A, and having its bent end resting lightly on the reed at E. The local circuit, starting from the battery, B, travels through the sounder, C, enters the reed at D, the rider through the contact-points. E, and the wire again at A, thence back to the other pole of battery B. When the reed is in vibration the local circuit is virtually broken at E by the rider being kicked off, and so much resistance put in at that point by reason of the very imperfect contact. The instant the reed comes to rest the adjusting spring pulls the rider down and closes the local circuit.

Consequently, when at the transmitting station all the vibrators act upon the battery, all the sounder circuits are opened. If, on the contrary, one of the vibrators stops, the sounder circuit of the corresponding reed is closed. The arrest of a vibrator then acts on its corresponding sounder as that of a Morse key would act, inserted with it, in the circuit of a battery.

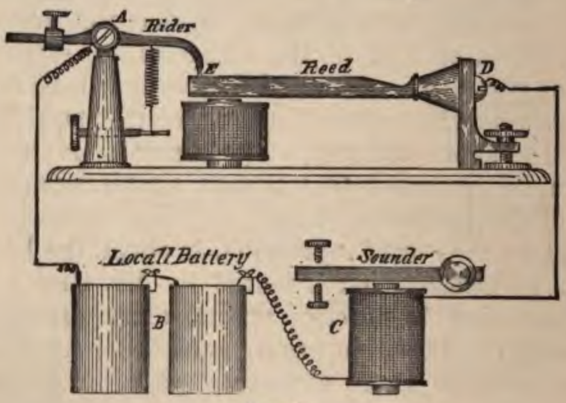

Fig. 89.

The vibrator is represented by Figure 90. The electro-magnets, A and B, have respectively one and thirty ohms resistance. The current of the battery, passing through the coils of the two electro-magnets, magnetizes them simultaneously, but on account of the greater number of convolutions the electro-magnet A is the stronger. It thus attracts the steel tongue which hangs from a fixed point between the magnet-cores. This tongue then makes contact by means of the spring D with the point C, establishing a shunt circuit round the magnet A, round which the current may now pass. The electro-magnet B becomes consequently stronger, and in its turn attracts the tongue until the spring F makes contact with the screw E. The contact D being broken anew, the electro-magnet A again attracts the steel tongue, and thus rapid motion is maintained. The tongue is then maintained in vibration, which is regulated according to its fundamental tone. The contact F represents one of the contacts indicated in Figure 88 by the letters C_1, C_2, C_3, and C_4.

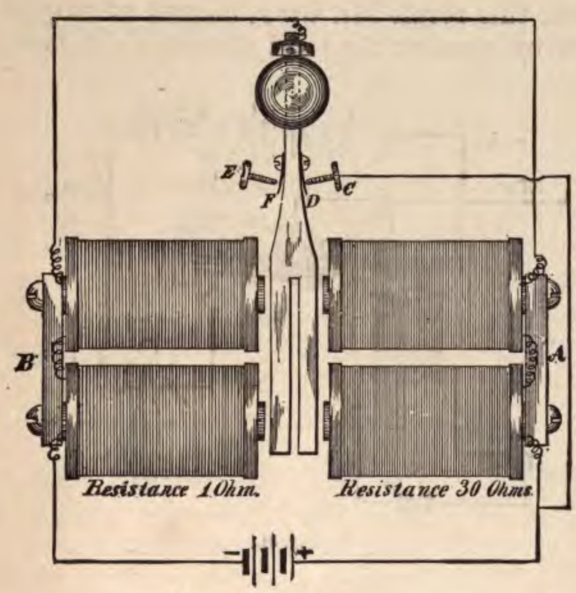

Fig. 90.

In the disposition of Figure 88, when the vibrator is in action by the operation of the battery which corresponds to it, it enfeebles this part of the battery in a proportion of about sixty per cent. When the vibrator is stopped its group of battery resumes all its force, and will tend to increase the intensity of the current in the line. With four vibrators, several among them being liable to be stopped at the same time, the changes of intensity would be very considerable and would injure the results derived from the system. In order that this latter effect may not take place it is necessary, at the same time that a vibrator be stopped, to suppress from the circuit the sixty per cent. of the group of the corresponding battery, in order to produce on the general current the same effect as the vibrator when it was in action. To attain this result Mr. Gray, instead of stopping the vibrator by opening the local circuit, which is the idea which presents itself naturally to the mind, produces this arrest by the aid of a special disposition called the transmitter, and represented by Figure 91. The principal part of this disposition is a lever of brass, A. It is terminated at one end in the form of a T. A spring, R, insulated by a piece of ebonite, is placed on the upper part of a lever, and a second spring, *r*, is in communication with the lower part. These two springs impinge at their extremities upon a branch of the T when they are not removed from it by one or other of the regulating faces, B and S. An electro-magnet, moved by the local battery, *p*, and a key, *k*, is placed above the armature of · lever.

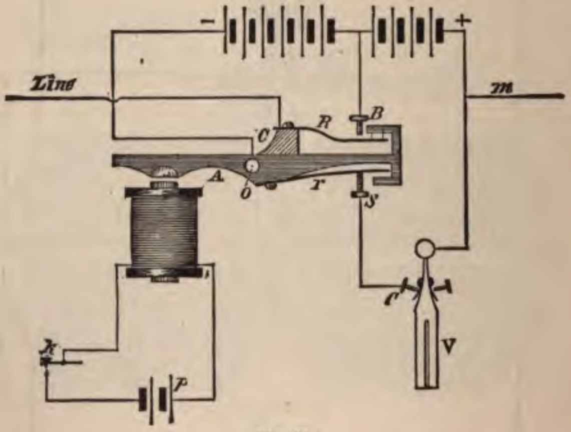

Fig. 91.

One of the extremities of the main battery is in communication with the axis, O, of the lever, the other with the vibrator and also with the adjoining instrument; the spring R is united to the line; the face S communicates with the contact, C, to the vibrator. Finally, face B is in relation with a point of the battery dividing this battery into two parts, which should be in ratio of sixty to forty.

In the position indicated by the figure the negative pole of the battery communicates with the line by the lever, A, and the spring, R; the positive pole communicates with the adjoining instrument. The contact, C, is thus in relation with the negative pole of the battery.

Then happens the arrangement shown in Figure 88, and the movements of the vibrating tongue act upon the battery to produce an undulatory current and to weaken this group about sixty per cent. It is so when the key, *k*, remains open; but when this key is closed the lever is attracted by the magnet, the spring *r* abandons the face S, and the spring R is supported upon the contact B, but ceases to touch the T of the lever.

The portion of the battery to the left of B is then excluded from the circuit, and it is only the portion at the right, or forty per cent. of the battery, which sends its current one way in the line by B and R, and the other way in the other adjoining transmitters by *m*. The sum total of the current has not changed, and the closing of *k* has the effect simply of suppressing the series of electrical waves corresponding to the vibrator, V, and consequently of stopping the corresponding vibrating reed.

It might be asked why the depression of the lever, A, is accomplished by the aid of a local circuit instead of being depressed directly. The reason for this is in the fact that the pressure of the hand would be very unsteady and the contacts would be irregular; with the attraction of an electro-magnet, however, on the other hand, the force producing the depression is always the same. If now the instruments are connected up in the manner described, we have the general plan shown in Figure 92. This part constitutes the Harmonic system, properly so called. It permits the transmission of four despatches simultaneously in a single direction—that is to say, from the transmitting station to the receiving station; but it is necessary that the employees at the receiving station be able to communicate with those at the transmitting station, in order to be able to respond to the calls or to make corrections.

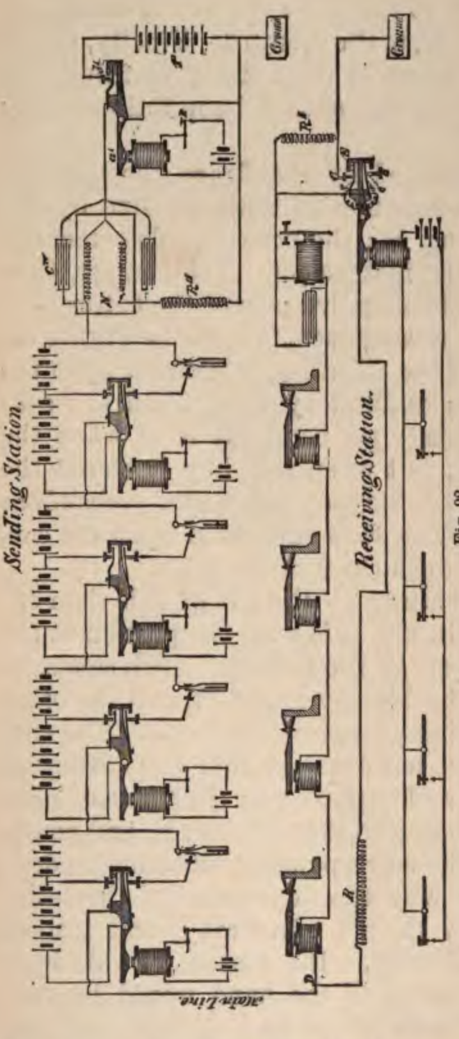

Fig. 92.

As shown in Figure 92, a differential relay is used at the sending station and a plain relay at the receiving station, each having a condenser in a shunt circuit around it to permit the vibrations to pass without being retarded or interfered with by the charging and discharging of the magnets. The compound transmitter at the receiving station will need some explanation. The two springs, S *s*, are both insulated from the lever by ebonite and connected together; the upper branch of the **T** is insulated from the spring S at E, and the lower spring, *s*, is insulated from the point *c* at *e*. The upper point C is connected directly to ground. R and R′ are adjustable resistances. R″ is the artificial circuit or equating resistance. When all are sending from the sending station, the current, after passing through the tone and simple relays, reaches ground through R′; that is to say, the circuit in its normal state has the artificial resistance of R′ constantly interposed. When it is necessary to break, which is done by operating the compound transmitter by one of the keys, the resistance R′ is thrown out of circuit and the current on the line is augmented in proportion to the amount of resistance contained in R′, which has been thrown from the circuit. The increased line current then divides at D, part of it going through the relays and the transmitter to ground from the point C, and part of it through R, the transmitter, and the point C. The resistance R is adjusted to shunt off part of the increased line current, and so maintain an unvarying strength through the relays regardless of the position of the transmitter lever. This decrease of resistance, however, throws the line out of balance and operates the relay N at the sending station, where the signals transmitted by any one of the breaking keys are reproduced. We thus have a sixth transmission in a direction opposite to the other five, and in practice the sixth side is used for breaking and other service work. As will be seen by reference to Figure 10, each receiving operator has a breaking key, and all of these work the compound transmitter, which operates the relay N at the distant station. This relay in turn controls as many sounders in its local circuit as there are sending operators. The sections are numbered in regular order from one to five at each end. When, for instance, No. 2 receiver wishes to break No. 2 sender, he simply makes the figure 2 on his key, which is heard on all the sounders at the other end, but only No. 2 sender stops work to get his break. Two or three hours' practice enables any operator to become accustomed to this method.

Condensers are placed in derived circuit upon each resistance. They have the effect of compensating the extra currents which are produced in the coils of the resistance, and which retard the undulatory currents ; in fact, they play the same *rôle* as in the Ruhmkorff or Ritchie induction-coils.

In Figure 92 the four groups of the battery are represented as being equal. In practice they are not so. All the groups are divided by the line running to the contact surface B, in two parts, which stand to each other in the ratio of sixty to forty ; but the absolute value of all the groups is not the same. The reason for this is in the fact, demonstrated by experience, that four pulsatory currents, produced by the action of four vibrators, are not produced with equal facility. The electromotive force necessary for their production is not the same for all ; hence the necessity for making the groups of different value.

The Harmonic system of Mr. Gray has been experimented with in this country from the 22d of November, 1880, to the 22d of January, 1881, upon the lines of the Western Union between New York and Boston, over a distance of 240 miles. The trial was made under unfavorable circumstances, for the line employed was in the vicinity of other lines upon which nine quadruplex circuits were working, and the currents of these instruments created difficulties in the way of induction in the neighboring wires, by reason of the employment of strong batteries and frequent changing of the poles of the battery. In one of the experiments five employees have transmitted, in the space of nine hours, 2,124 despatches, or 236 despatches in all per hour, or 47 de-
hes per operator per hour. Another time four
ees, chosen among the best, transmitted, in five

hours, 1,184 despatches, or 59 per employee per hour. After these experiments, the franchises required by a company which is occupied with the construction of special lines to operate in competition with the existing telegraph companies in this country, were acquired. The Duplex, or Way Harmonic, which is a modification of the system which we have just described, is already employed on several railroads.

At least five experimenters worked in the line of Harmonic telegraphy during the years between 1870 and 1876 inclusive—viz., Varley of London, La Cour of Copenhagen, Gray of Chicago, Bell of Boston, and Edison of New York. And, although Mr. Varley was the earliest in the field, Mr. Gray has done so much to develop Harmonic telegraphy, and make it not only practicable but also practical, that it seems but fair to award him the greatest share of the credit.*

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*Since the above was written the Harmonic system has successfully been operated over the low-resistance compound wire of the Postal Telegraph Company between New York and Chicago, a distance of one thousand and twenty miles, without the intervention of repeaters.

CHAPTER XVIII.

MISCELLANEOUS APPLICATIONS OF ELECTRICITY—ELECTRIC LIGHTING.

233. *To what useful arts, besides telegraphy, has electricity been applied?*

It is impossible in a work of this general nature to enumerate all the useful applications of electricity; its principal applications are, however, the following: electric lighting, electro-plating, electro-typing, bell-ringing and signalling, telephony, medical applications, or therapeutics, clocks, blasting, and gas-lighting.

234. *What is the electric light, and under what divisions may electric lights be classed?*

By the electric light is meant any light produced by the action of electricity, and all such lights up to the present time may be regarded as belonging to the following divisions: *arc* lights, *incandescent* lights, and *semi-incandescent* lights. The so-called electric candles are, properly speaking, but a special variety of the arc.

235. *What is the arc light?*

It is the extremely brilliant light produced when the two conductors leading from the poles of a powerful source of electricity are brought together so as to complete the circuit, and then slightly separated. It is, as shown in Figures 93 and 94, of curved form when produced in the open air, by means of horizontal electrodes, and is for that reason originally called an arc.

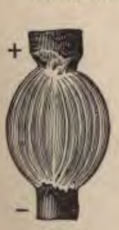

Fig. 93.

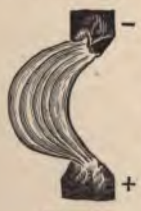

Fig. 94.

The more powerful the source the greater may be the length or span of the arc, and the more intense and brilliant the light emitted by it. If the two severed ends of the circuit are made of carbon, and pointed, the effect is materially augmented. The arc is supposed to originate in the passage between the electrodes of the self-induced extra current, which attempts to leap from one carbon to another, and in doing so volatilizes a small amount of carbon. The carbon vapor thus produced has a very high resistance, and, while capable of conducting the current, becomes heated by its passage, the carbon points also growing hot. Numerous small particles of carbon are then thrown from one pole of the arc to the other, and during their transit become incandescent, thus aiding in the illumination. The direction in which the particles move is dependent upon the direction of the current; that is, from the electrode or conductor leading from the positive, to that leading from the negative pole.

The positive terminal of an arc light is much hotter than the negative, and is consumed much faster. When enclosed in a vacuum, the consumption of both electrodes is much less rapid than when the arc is exposed to the air.

For illuminating purposes the electrodes are nearly always made of carbon. The color of the luminous arc depends on the material of the electrodes; for example, carbon produces a white, copper or silver a green, and sodium a blue light. The electricity traverses the arc, which is, therefore, a part of the circuit.

The arc was first produced by Sir Humphry Davy, by means of large voltaic batteries, from which the name *voltaic arc*, often applied to it, is derived.

The following lines are transcribed from the work of Professor Silvanus P. Thompson: "The resistance of the arc may vary, according to circumstances, from five-tenths of an ohm to nearly one hundred ohms. To produce an electric light satisfactorily, a minimum electromotive force of forty to fifty volts is necessary; and as the current must be at least from five to ten ampères, it is clear that the internal resistance of the battery or generator must be kept small. With weaker currents, or smaller electro-motive forces, it is impracticable to maintain a steady arc. Therefore the internal resistance of the ordinary Daniell or Leclanché batteries is too great to admit of their use in producing the electric light. A battery of forty to sixty Grove cells will answer the purpose, but will only work well for two or three hours.

Had no other method of producing current electricity been discovered, the art of electric lighting would still have been only an electrical curiosity; but the numerous forms of dynamo-electric machines recently invented have made the production of the electric light comparatively cheap, and have given the art a great impetus. It will be readily seen, however, that to apply the name voltaic arc to an electric arc produced by electricity evolved by a machine is a palpable incongruity. In Davy's experiments, about the beginning of the present century, he produced a light with an arc four inches long, in the open air, by using a battery of some two thousand cells.

236. *What is an electric-arc lamp?*

An electric-arc lamp, frequently called a *regulator*, is a device or apparatus constructed for the purpose of maintaining the electrodes of the arc at their proper distance from one another. Such a contrivance becomes necessary, because the carbons are continually burning away, and if some means were not adopted for carrying them forward, and keeping them at the proper distance apart, the light would soon be extinguished.

Much ingenuity has been displayed in the construction of these lamps and regulators, and many extraordinary arrangements have been devised, only a few of which have survived and gone into extensive use.

"In some of these the carbons are attached to guides actuated by trains of wheels, which push them forward at the necessary speed. The wheels are put in action or stopped, as the case may be, by means of electro-magnets forming part of the electric circuit of the lamp. Most of these electric lamps are arranged so that when the lamp, from any cause, goes out, the carbons are brought into contact for an instant, and as soon as the current is thus re-established the carbons are drawn back to the required distance." *

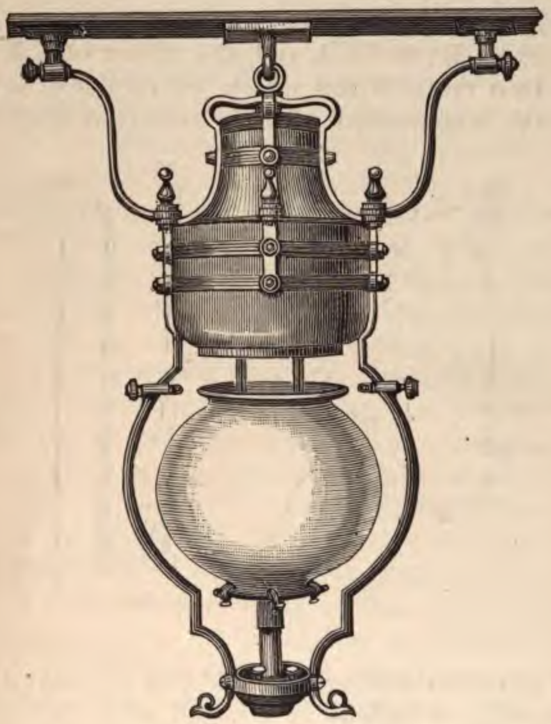

Fig. 95.

The movement which is most frequently used in America is one wherein the attraction of a solenoid, acting upon a movable iron core, regulates the distance between the carbons. Such a lamp is that of C. F. Brush, which is shown in Figure 95, and which, be-

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* "Electric Light," by A. Bromley Holmes.

sides being capable of regulating the distance between the carbons, automatically short-circuits, or cuts itself out, when defective, thus permitting the current to flow, as it were, round the lamp in the main circuit.

As this lamp is quite extensively used, its operation will be fully described.

The circuits are shown in the diagram, Figure 96; the lower carbon, K′, is fixed, and the upper one, K, is attached to a metallic rod which, by means of a washer clutch, W, is connected with an armature carried by a pair of plungers, arranged to slide in and out of a pair of solenoids, or helices of covered wire, H H. These solenoids are wound in multiple arc with two wires, which are wound oppositely with respect to one another. The first of these wires is in direct circuit with the arc, and consists of a few layers of coarse wire, through which the main portion of the current operating the lamp passes to the rod of the upper carbon. The upper carbon falls by the action of gravity against the lower carbon, and when the two carbons are together the current passes on from the upper to the lower, and thence out.

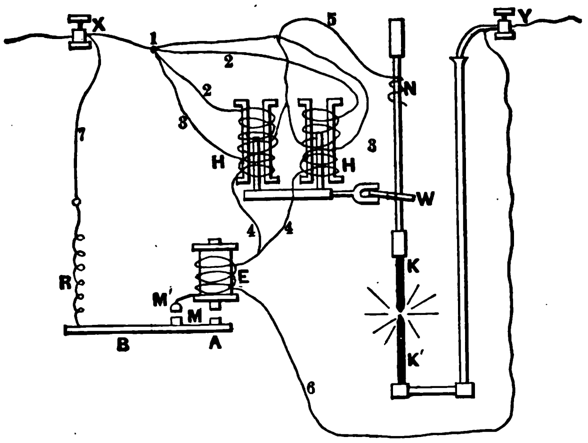

Fig. 96.

Entering the lamp at the binding-post X, the path of the circuits, which are three in number, are as follows: The circuit through the lamp carbons is from the point 1, by the parallel wires 2, constituting the coarse-wire helix round the solenoids, H, and by the wire 5 to the carbon-holder, N, and thus through the arc to the terminal, Y, and on to the next lamp. The second circuit is composed of much finer wire, and, branching from the main line at the point 1, passes by the parallel wires 3 through the solenoids, being in practice wound over the layers of coarse wire; issuing from thence by the wires 4, it is led round the electro-magnet, E, and out to the binding-post Y by the wire 6.

Thus the fine wire forms a secondary circuit of high resistance through the lamp, which circuit is independent of the arc between the carbons, and is always closed. It follows from the difference in direction of the current in the two helices, that the fine-wire helix will constantly tend to neutralize the magnetism produced by the coarse-wire or principal helix. The number of convolutions of the fine-wire helix and its resistance are so proportioned to the number of convolutions in the principal helix, and its resistance together with that of the normal voltaic arc, that the magnetizing power of the latter shall be much greater than that of the former. Notwithstanding the small amount of current which passes through the fine-wire helix (about one per cent. of the whole current), its magnetic power is very considerable owing to its great number of convolutions.

Now, when the arc of any lamp becomes too long the resistance of its main circuit is thereby increased and more current is sent through the secondary or fine-wire coil; the magnetizing power of the solenoid, of course, being thereby weakened, allowing the carbons to approach. On the other hand, if the arc becomes too short its resistance is reduced, less current goes through the fine-wire helix, and the magnetic strength of the solenoids are correspondingly increased. The plungers are sucked into them, carrying the armature, H, and lifting one end of the ring-clutch, W, and the upper carbon-holder with it, and thus the arc is maintained. In practice the resistance of the fine-wire helix or helices in each lamp is rather more than 450 ohms, while the resistance of the coarse wire, various connections, carbons, and voltaic arc, in each lamp used with the sixteen-light machine, is about 4.5 ohms. Hence not more than 1 per cent. of the whole current is diverted from the arc. The resistance of the coarse-wire helix, carbons (copper-coated), connections, etc., in each lamp is very small. To determine this resistance 16 lamps were connected in series in the usual manner, about 200 feet of No. 10 copper circuit wire being used. Full-length carbons were then placed in the lamps, and the upper and lower carbon of each lamp were connected by means of a strip of sheet copper wired to each carbon. The resistance of the whole set was then measured and found to be 2.10 ohms, showing a resistance for each lamp with its carbons of 0.131 ohm. This is 2.91 per cent. of the whole resistance of the lamp when in operation. To this loss must be added the 1 per cent. due to that amount of current diverted from the arc by the fine-wire regulating helix, making a total loss of 3.91 per cent. The remaining 96.09 per cent. of the whole energy absorbed in each lamp appears in the arc between its carbons. The third branch circuit through the lamp is only completed when the resistance in the arc becomes abnormally great, or when the arc from any reason fails.

It constitutes the short-circuiting or cut-out device, and is operated by the electro-magnet, E. The core of this magnet is surrounded by two coils just like the solenoids, but, unlike them, its coils are both wound in the same direction. The fine-wire coil, as already described, is a continuation of the fine-wire solenoid helix. The thick-wire coil, which is only brought into action when the lamp is to be cut out, starts from the stud, M′, passes round the core, and then unites with the terminal wire 6 of the fine coil, passing out to Y. The armature, B, of the electro-magnet, E, connects by a suitable wire, 7 R, with the screw-post, X.

The armature-lever of the electro-magnet is suitably pivoted, and is united by the wire R, which may be made of any required resistance, to the incoming line-wire before it reaches the solenoids. If now the arc fails or if its resistance is excessively increased, a large proportion of the current goes through the fine wire of the electro-magnet, which thus becomes more strongly magnetic, and strong enough to attract its armature. The armature, being attracted, closes the circuit of the thick wire. If the trouble in the arc is permanent the short circuit is now maintained through the thick wire cutting the arc completely out. If, on the contrary, it was merely caused by the undue length of the arc, as soon as the short circuit is made through the thick wire of the electro-magnet the solenoids lose their power, the upper carbon falls on the lower one, the electro-magnet in its turn is short-circuited, the solenoids resume their power, and the light is reinstated by reason of the carbons taking their proper distance apart. The entire series of operations, though taking a long time to describe, are the work of an instant, so that the light, though subject to continuous regulation, is practically maintained without any cessation, except when completely disabled; when it is immediately short-circuited.

The lamp thus described, and all of the types treated of in the above explanation, are of course adapted only for the production of the arc light, and where other varieties of electric light are required other forms of lamp become necessary.

237. *What is meant by the incandescent electric light?*

The incandescent light is that produced by the passage of a strong current of electricity through an imperfect conductor or a conductor of high resistance.

It is based upon the principle that when such a current is passed through such a conductor the substance of the conductor becomes heated; and if it be attenuated—as, for example, in the case of a piece of fine wire or a thin carbon pencil or filament—after a certain degree of heat is reached, say above two thousand degrees Fahrenheit, it glows with light, the brilliancy of the light depending upon the strength of the current.

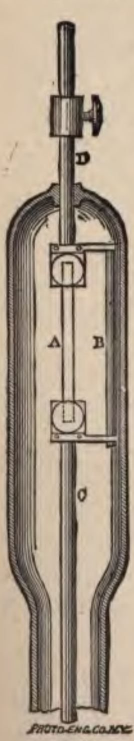

Fig. 97.

Lighting by incandescence has ever been a favorite idea of inventors and experimentalists in electric lighting, but only within the last few years can it be said to have achieved any important success. Contrary to the general opinion, this idea is by no means new, since as early as 1845 an American inventor named Starr patented in England a lamp which is shown in Figure 97, and which was intended to operate on this principle.

This lamp consisted of a conducting wire, D, sealed into one end of a glass Torricellian vacuum-tube, and connecting with a carbon rod, A, whose lower extremity is in contact with a second conductor, C, which rests in the quicksilver. A non-conducting bar, B, carries brackets in which the carbons are supported. The subject, after temporary revivals in 1850 and 1852, dropped out of sight, chiefly on account of the lack of an economical generator of electricity; but in 1873 was again taken up by Lodyguine, a Russian inventor.

Since then it has assumed a steadily increasing importance, Edison, Weston, Maxim, Sawyer, and Bernstein working upon it in America, and Swan and Lane-Fox in England.

Considerable success has attended their efforts, and one of the most, perhaps *the* most important installation, is that of Mr. Edison, who, after many months of patient and continuous labor, has succeeded in illuminating a number of business places and houses throughout an extensive district in New York City from a single central lighting station.

After many experiments with iridium and platinum, or alloys combining or containing these metals, all the inventors ultimately have decided that carbon is the only suitable known substance to maintain in the incandescent state as an illuminator. Experience has also demonstrated that some method of protecting the light-giving part from the oxygen of the atmosphere is necessary, the carbon otherwise being rapidly consumed. For this reason Edison, Swan, Lane-Fox, Weston, Maxim, and Bernstein use lamps in which the deleterious action of the oxygen is prevented by enclosing the incandescing conductor in vacuo; while Sawyer encloses his carbons in globes filled with nitrogen.

238. *What are the distinctive features of the different incandescent electric lamps?*

The Edison lamp, as now made, has for a light-producing part a carbonized filament of bamboo. This is enclosed in an exhausted glass globe, and by means of fine platinum wires is connected to a screw and sole-plate, which, when screwed on to a bracket or stand, make contact with the two external conducting wires. In the construction of these carbon filaments Mr. Edison made many experiments to ascertain the best material to be employed, and, after carbonizing a large number of vegetable fibres and tissues, arrived at the conclusion that certain kinds of bamboo presented the greatest advantages, both for facility of manipulation and for uniformity of structure. The shape of the carbon filament used in this lamp is that of an inverted U, as shown in Figure 98.

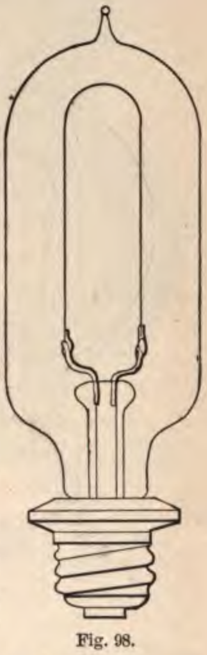

Fig. 98.

The Swan lamp-carbon is formed of cotton thread converted by treatment with sulphuric acid into a parchment-like material, and carbonized. The finished carbon is looped with a double turn at the top, as in Figure 99. The ends of the strip are thicker than the middle, and are joined to the conducting wires by metal clamps.

The Lane-Fox lamp is represented by Figure 100, and in it the carbon filament is made from the fibres of Italian grass, or bass-broom. A peculiar method of rbonizing is involved in its preparation.

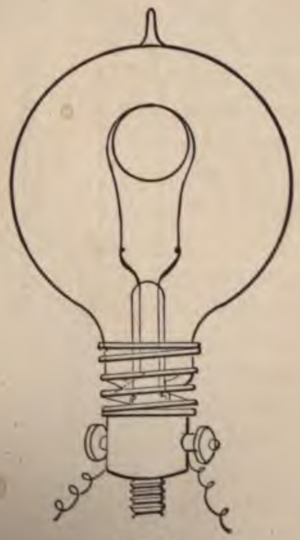

Fig. 99.

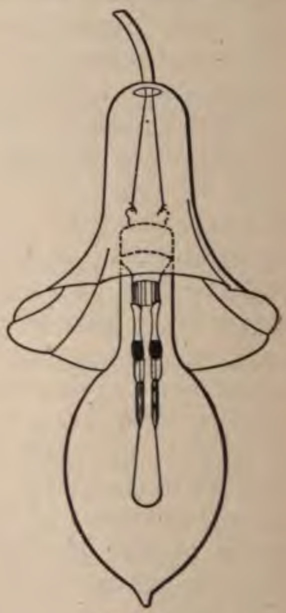

Fig. 100.

Figure 101 shows the Maxim lamp, which is distinished by an incandescing carbon made from cardard and shaped like the letter M.

The light giving conductor in the Bernstein lamp consists of a hollow cylinder of carbon supported at each nd in a carbon socket.

The Weston lamp is similar in appearance to the Maxim, but the filament is made of non-fibrous cellulose, which is afterward carbonized. This material is extremely tough and elastic, and has a high resistance.

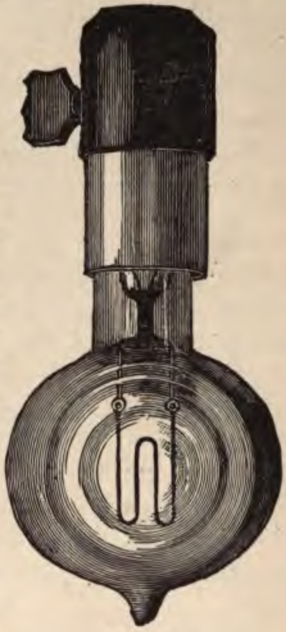

Fig. 101.

239. *How is the illuminating power of a light generally expressed?*

The standard unit of measurement of light in this country and England is a sperm candle burning approximately one hundred and twenty grains of spermaceti per hour. In France the carcel lamp is the unit; this lamp burns forty-two grammes, or six hundred and forty-eight grains, per hour. In Germany the unit is a paraffine candle of which six weigh five hundred grammes; one carcel is equal to about seven and one-half of these candles. All of these standards are crude approximations, and it has been suggested among other plans that the unit should be derived from the area of floor which any light is capable of illuminating.

240. *What is meant by the term electric candle?*

The electric candle is really nothing more than a peculiar arc lamp reduced to its simplest form. It consists of a pair of small carbon-rods placed parallel to each other, with a thin strip of plaster-of-Paris or fine clay between them as an insulator. This being in the shape of a candle, together with the fact that the light commences at the free ends and burns downward as the carbons consume away from one end, like the wick and combustible material of a candle, account for the name. The candle is the invention of a Russian engineer, M. Jablochkoff, and was patented by him in March, 1876.

Its use dispensed with the cumbrous and complicated lamps and regulators then in use, and gave an impetus to electric lighting which is still felt. The sticks of carbon which constitute the candle are only about one-sixth of an inch in diameter and from nine to ten inches in length, although they have been made as short as six and a half inches. The shorter ones only burn one hour. When the current of electricity passes, an arc of light is maintained across the top of the carbons, which are gradually consumed as an ordinary candle is, together with the insulating material. The circuit before the current passes is completed, and the candle lighted by laying a small piece of graphite or black lead across the top of the carbon sticks. The currents employed are of an alternating character, so as to consume both of the carbon sticks equally fast. These candles are more used in France than elsewhere, although they have been employed to a considerable extent in London. Four candles are usually placed in an opalescent glass globe, and an automatic arrangement provided to switch the current from one candle to the next as each burns down.

The electric candle has been much improved by the well-known electrician and inventor, Mr. Henry Wilde, of Manchester. He remarked the small part apparently taken by the insulating material, and diminished that material by discontinuing the plaster-of-Paris and merely coating the carbons with a hydrate of lime. No difference in the operation of the candle being observed, he went a step farther and arranged the carbons without any insulator or separating medium at all, finding the light to be absolutely improved thereby. He further observed that even when the circuit was completed at the bottom or lower end of a pair of carbons, the arc or light would immediately ascend to the points. He next arranged an automatic lighting device by making one of the carbon-holders with a hinge at the bottom, and continuing it horizontally in the form of a right-angled lever, the horizontal part serving as the armature of an electro-magnet, the helices of which are included in the lighting circuit. By its weight the carbon, and its holder, which is hinged, lean against the fixed carbon as long as no current is flowing; but as soon as a current commences to flow, the circuit being completed at the point where the carbons touch one another, the electro-magnet is charged, attracts the armature, and draws the hinged carbon-holder to an upright position, and so brings the carbons to the requisite distance from one another.

241. *What are semi-incandescent electric lights?*

These, which are also sometimes called incandescence-arc lamps, are constructed either by arranging a carbon rod to press against a block of carbon, or by having two carbon electrodes, with a piece of refractory non-conducting material, such as marble, interposed between them.

In the first case the light is produced by the passage of the current through a rod of carbon, which, at the end that presses against the block, is so small that its extremity becomes heated nearly to whiteness.

Also, when the pressure is very slight, small arcs are developed at the point of contact, which aid in producing the light.

Of this category are the lamps of Regnier, Werdermann, and Varley.

In Werdermann's lamp a rod of carbon is forced upwards by the action of a weight against a rounded block of carbon; the rod becomes incandescent at its extremity, gives a strong light, and is gradually consumed. Varley's lamp is one of the earliest of this class, and consists of a disc of carbon with bevelled edge, on which rests the extremity of a carbon pencil mounted at the lower end of a pivoted lever. Regnier's lamp is an improvement on the foregoing, and comprises a rod and a disc of carbon; the rod as it falls imparts motion to the disc, which is thus caused to revolve, and continually presents fresh points of contact.

In the second case the light results from the passage of the electricity over the surface of the block of marble, or other analogous substance, which is between the carbon electrodes. This, by the intense heat, is made incandescent, and its incandescence adds to the light of the arc between the electrodes. The most familiar lamp of this class is called the Sun Lamp (Lampe Soleil). This light is very steady, is of a golden hue, and has an advantage in the stored-up heat in the incandescent block, which, if the current weakens momentarily—for example, by reason of a slackened driving-belt—is sufficient to supply the deficiency for a short time. It is said, however, to be very wasteful of power.

The earliest worker in both of these classes was W. E. Staite, of London, who, between the years 1846 and 1849, took out several patents in England for different plans of electrical illumination.

CHAPTER XIX.

ELECTRO-METALLURGY.

242. *What is electro-metallurgy?*

It is the art which governs the electro-deposition of metals upon any surface prepared to receive them, from a metallic solution. It is based upon the observed fact that a current of electricity passed through such a solution tends to decompose it into its constituents—water and the metal held in solution; depositing the latter, as before stated, upon any prepared surface. The two great divisions of electro-metallurgy are electro-plating and electro-typing.

243. *What is electro-plating?*

It is that division of the art of electro-metallic deposition which treats of depositing a permanent coating of metal by means of electricity. Although we are accustomed to speak of electro-plating only when referring to the deposition of silver and gold, we may with perfect correctness apply the term to any other metal also.

To electro-plate is to provide a chemically clean metallic surface, to immerse that surface in a metallic solution, and by means of electricity to cause the metal contained in the solution to be deposited upon the immersed surface in such a manner that it may permanently incorporate itself with the original surface; and so, whatever may be the material of which the original surface is composed, after plating it will appear like whatever metal is deposited on it, whether that metal be silver, gold, copper, nickel, or anything else. As already indicated, the article to be plated must be chemically clean. The source of electricity employed may be either a voltaic battery or a dynamo-electric machine. If the plating establishment is a commercial one or doing business on a large scale, a machine is decidedly to be preferred. For experimental work a battery is the most convenient. For most work of the ordinary character, either in copper, silver, or nickel, the large Smee battery is most universally useful. The Daniell battery may be used for small current work, such as gilding; and the carbon battery can be profitably employed where a strong current is required, as in depositing brass or iron.

The process is represented in Figure 102, where O is

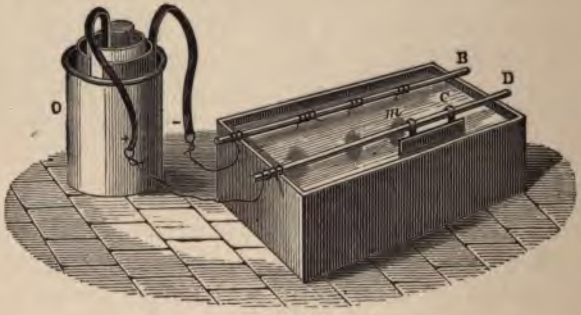

Fig. 102.

the depositing battery, C the vessel containing the solution, D a metallic rod connected with the positive pole, having a plate of metal suspended from it and dipping into the liquid; B is another rod, connected with the negative pole of the battery, and from which the articles to be plated are suspended. These articles are thus made the negative pole of the battery, and the metal plate suspended from D becomes the positive pole.

The dynamo-electric machine has within the last ten years to a great extent superseded the batteries in factories, and the forms of machine favored are chiefly those of Gramme and Weston, but any dynamo machine of small internal resistance, furnishing constant currents of non-alternating direction, may be successfully used.

Electro-plating is one of the most useful of arts, and serves either to protect a valuable surface, or to beautify a surface, or ornament and give an appearance of value to articles of ordinary character.

244. *What is electro-typing?*

By electro-typing is meant the production of copies in metal of any object by means of the action of electricity. It differs from electro-plating in that the metal deposited on the article subjected to the process is not intended to remain permanently, but merely, as it were, to form itself upon, and assume the shape of, that article. While the electrical features are the same as in electro-plating, and while the art is dependent upon exactly the same principle, the technical details are completely dissimilar, since in the former art all the skill of the operator is directed to the establishment of a permanent adherent coating of metal, while in electro-typing his efforts are oppositely directed, and all the details of the process must be arranged to admit of a ready separation of the deposited metal from the original article.

245. *Give a brief outline of the art of electro-typing.*

This art was first introduced as early as 1838 by Professor Jacobi, of St. Petersburg, in a paper communicated by him to the Academy of Sciences of that city, in which he explained a process of producing copies of engraved plates by means of electricity.

Almost at the same time Mr. Thomas Spencer, of Liverpool, made public a series of experiments in which he had been engaged on the same subject; while nearly simultaneously a printer named Jordan described similar experiments which he had made about the same time. In this, as in other great discoveries, it thus appears that several experimentalists were close to each other on the same track at once; but Spencer was by far the most painstaking of the three, and demonstrated its practical value.

The entire process is founded upon a very simple principle—namely, that certain metals can be deposited from a solution of their salts by the passage through that solution of a current of electricity. The primitive methods adopted in the early days of the art are now obsolete, except as used by amateurs; nevertheless, as they embody the above principle as well as the most recent modes can do, and also possess the cardinal virtue of simplicity, they are here noticed.

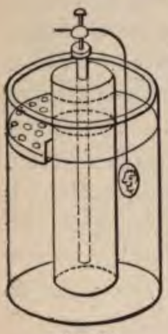

Fig. 103.

A modification of the Daniell battery, such as is shown in Figure 103, was generally used, consisting of a glazed earthenware or glass cell containing a solution of sulphate of copper, kept at the proper strength by extra crystals on a shelf. A porous cup containing dilute sulphuric acid stood in the jar, holding an amalgamated zinc rod. The object to be copied, or electro-typed, whether a coin, medal, a seal, or other article, was attached by a copper wire to the zinc of the battery and suspended in the solution. This object thus formed the negative plate of the voltaic cell, and an electrical current passed from the zinc, through the two liquids and the porous cup, to the object to be copied, and back to the zinc rod through the wire, completing the circuit. When the circuit was closed the zinc dissolved and formed its sulphate; the copper solution was also decomposed and its copper deposited on the object to be copied. Any part not required to be copied was coated with varnish or some other non-conductor. The deposit was separated from the object when sufficiently thick, and found to be an exact fac-simile of the original article.

Such is the art of electro-typing in its crudest methods, but substantially identical in every essential feature to the same art as practised with every modern appliance. If the model be not a conductor it becomes necessary to coat the surface to be copied with some metallic powder (black-lead is generally used), applied over the surface with a fine brush. It is evident that by this device we are enabled to use as models plaster-of-Paris, wax, gutta-percha, or any fusible or plastic substance. It was early discovered that the use of a separate battery, as shown in Figure 104, was a great improvement; when this was used a bath of the solution of the metal to be deposited was prepared, and the copper plate of the battery connected with a second copper plate suspended in the solution, while the articles to be copied were also suspended in the solution and united by a wire to the zinc plate of the battery. When so disposed the suspended copper plate dissolves, adding copper to the solution as fast as it is abstracted from it by deposition on the articles to be copied. As in the sister process of electro-plating, the use as a generator of the dynamo-electric machine has greatly advanced of late years, and it is now employed in all large establishments.

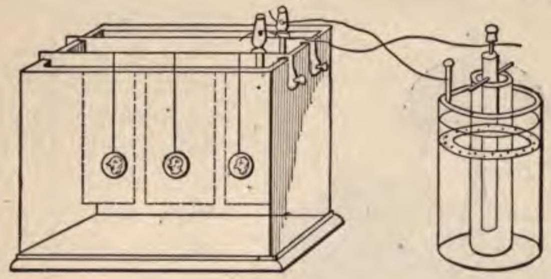
Fig. 104.

The electro-typing process finds many uses: it is universally employed to produce copper duplicates of wood engravings, and set-up type is often thus copied; statuettes, medals, and coins can be thus reproduced without limit, and many electro-type copies are fully as beautiful as the originals.

CHAPTER XX.

ELECTRIC BELLS.

246. *How is electricity made to ring bells?*

Practically in the same way in which it is made to operate a telegraph. An electro-magnet is fitted with an armature; that armature is pivoted, and its lever extended to the necessary length and furnished at its free end with a bell-hammer, which, when the electro-magnet is excited and the armature consequently attracted, strikes upon a gong with more or less force. This is shown by the engraving, Figure 105.

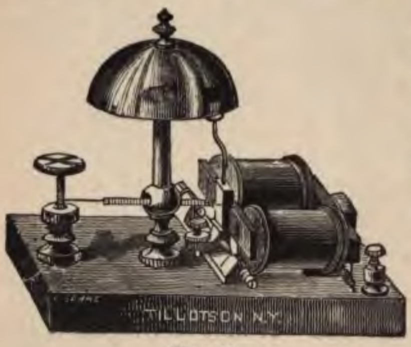
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Fig. 105.

There are several ways in which electricity may be utilized for this purpose. The method already described may be varied by so disposing the several parts that the armature and hammer are attracted away from the gong when the electro-magnet is charged by the closing of the circuit, while when the circuit is again broken the hammer, being retracted by a spring, strikes the gong. Sometimes the bell is so constructed as to ring when the direction of the current is reversed, and the bell is then called a polarized bell. At other times, when a heavy stroke is required, while the power exerted by the current is but feeble, the hammer is impelled by a weight or spring acting through a train of clock-work, the electricity in such cases merely acting as a controller to release and detain the clockwork.

247. *What is a single-stroke electric bell?*

It is a bell comprising an electro-magnet, an armature operated by the same, and a hammer extending from the armature, which may be arranged to strike its gong a single stroke or tap at the moment either of breaking or making the circuit; of changing the direction of the current; or both; at the will of the manipulator. The name *single-stroke* is colloquially applied to such a bell in contradistinction to a bell giving a *continuous* ring.

248. *What is a vibrating or trembling electric bell?*

It is an electric bell which, in addition to the elements possessed by the single-stroke bell, has some device adapted to alternately allow the electricity to pass through the electro-magnet helices and shut it off from them, so that as soon as the hammer is so far drawn up as to strike the bell it is drawn back again once more to be attracted, and again withdrawn, and so on as long as the circuit is kept closed at the point of manipulation; that is, if a bell of this character be placed in the circuit of a battery, the said circuit also passing through a key which is normally open, when the circuit is closed by pressing the key, the magnet will become charged and will attract the armature, and the bell-hammer attached to the armature will commence to alternately strike the bell and withdraw from it, and continue so to do until the key is once more opened.

This kind of bell usually is arranged by leading the circuit of the bell-magnet through the armature-lever itself, and from it to the back limit-stop, thence to the binding-post; thus when the armature is attracted under the influence of the current, it has only time to strike the gong before the circuit is broken by the withdrawal of the lever from the back limit, and it is compelled to recede. The lever is usually furnished with a platinized spring, which improves the contact, and at the same time gives the armature an impulse and prevents it from breaking the circuit prematurely. Figure 106 represents one of the most frequent forms of the vibrating bell. There are several other ways of constructing vibrating bells, but the foregoing is for ordinary use the best way.

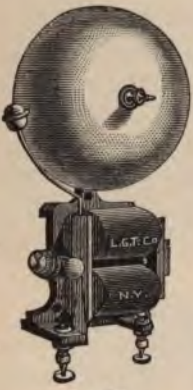

Fig. 106.

249. *How is a polarized bell constructed?*

Quite a variety of polarized bells are made, and used for special purposes. Two, however, are sufficient to exemplify the principle. The first, and until the days of the telephone the most usual form, has substantially the same construction as a Siemens polarized relay (Q. 192).

A base of hard steel is made in the shape of a right angle; on the horizontal or flat side of the steel base an electro-magnet is transversely placed, so that if the end of the flat side is of north polarity the same polarity is by induction continued through the electro-magnet, and both of its poles become north poles. The other end of the angular steel magnet is, of course, a south pole, and is forked; one end of a slender rod of iron is pivoted in this fork, and the other extends outwardly until its end rests between the two extremities of the electro-magnet, which are fitted with adjustable pole-pieces.

As shown in Figure 107, which represents a modification of this type of polarized bell, an extension-rod provided with a hammer is attached to the end of the iron rod which serves as an armature, and in its range a bell is placed. When the electric impulses sent from a magneto-generator, or a battery and pole-changer, are passed through the coils of the bell-magnet, the armature vibrates from side to side and rings the bell.

Such a bell, though strong and reliable where comparatively slow alternations of current are sent, is rather sluggish in its action when the alternations of direction are very rapid. This fact led to the introduction of the second form of polarized bell, which is now to be described. This is the form so familiar to us in the regulation telephone bell-box. In this bell, as in the one already described, an electro-magnet is fixed upon one end of a permanent magnet, while near, but not necessarily attached to the other end of the permanent magnet, a soft-iron armature is pivoted by its centre, and carries by a light metal rod the bell-hammer. The permanent magnet is in shape like a bar magnet, with each end bent for about an inch at right angles to itself; one of these bent ends is placed behind the heel-piece of the electro-magnet, and the other behind the centre of the pivoted armature. Two gongs are arranged in front, between

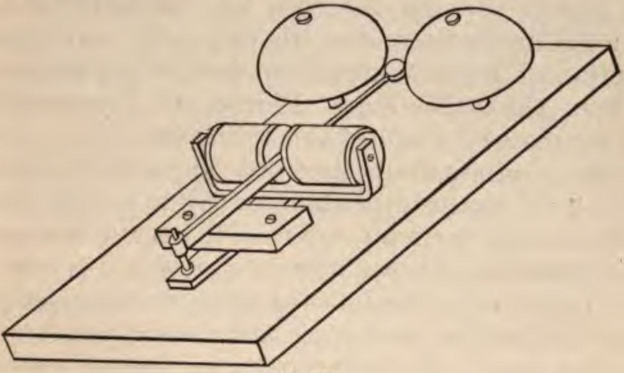

Fig. 107.

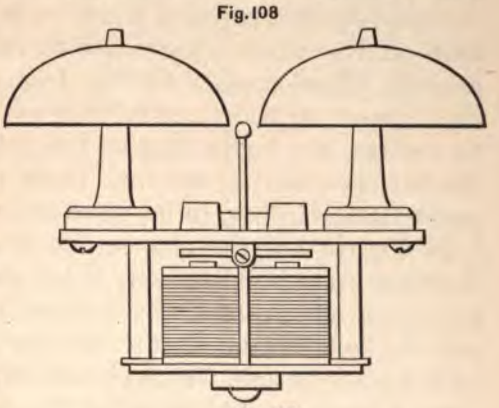

Fig. 108.

which the bell-hammer vibrates, striking each alternately. When an electric pulsation of positive direction is sent through the coils of the electro-magnet the armature swings over to one side, and when a pulsation of negative direction is sent it swings over again to the other side. Figure 108 represents the working parts of a bell ~~of~~ this character.

Rapidly alternating electrical currents, generated either by a magneto-machine or by a battery having a pole-changer in circuit, are used to operate these bells, and in practice a generating magnet and coil is attached to each one, and placed in the same case, immediately below the bell, so that each instrument possesses not only the power of ringing but also that of operating other bells.

250. *How must the apparatus and wires be arranged for a simple bell circuit, where one bell is to be rung from but one point, and what apparatus is required?*

All that is required is one bell, one press-button, or key, as much battery as may be found necessary (for any distance short of fifty feet one cell of Leclanché will do), and enough wire for about twice the distance between the button and the bell. To set up the apparatus, screw up the bell to a support where it is wanted, then measure off the wire, taking care to have the pieces long enough. Find a place for the battery and set that up; then attach to the terminal screws of the press-button two wires, one extending to the bell, and the other to the battery; having attached them to the press-button, screw up the button in its place and put on its cover.

In Figure 109 the connections are clearly shown, H indicating the bell-hammer, E the electro-magnet, C the automatic circuit-breaking points, P the press-button, and B the battery. Figure 110 shows a vertical section of the press-button, which clearly explains its operation. One of the press-button wires is connected with one of the bell binding-screws, and the other to one pole of the battery. A third wire must now be made to unite the remaining bell terminal to the other battery pole; this done, the construction is complete. The circuit may now, referring to the figure, be readily traced: commencing at the positive pole of the battery, and following the arrows, the circuit is first to the press-button, where it is ordinarily open, then to one of the bell terminals, through the bell-magnet to the armature-lever, through the lever to the points C, then to the outgoing terminal, and thence back to the negative pole of the battery.

For good work the wires must be well insulated by being covered with cotton, or, if they are to rest in damp places, with kerite or india-rubber; of course, before making connections, the ends of the wire must be carefully stripped for about an inch and a half. The wires should be neatly tacked to the walls, or otherwise secured. More than one wire must never be placed under one staple, and the entire work must be made as neat as possible. It is just as easy to make a handsome job as an unsightly one. This is the simplest plan for a signal-bell circuit, and may readily be constructed by any one.

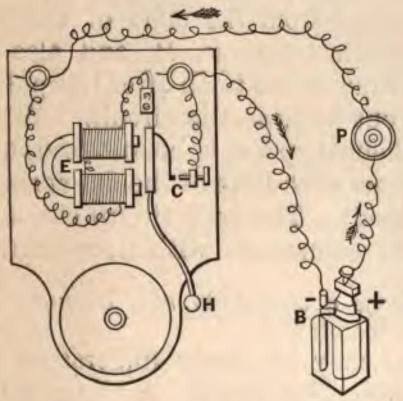

Fig. 109.

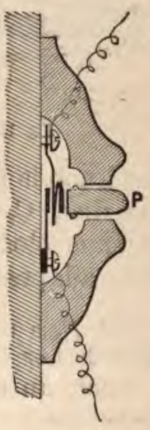

Fig. 110.

251. *How may electric bells be operated by a pull, similar to the ordinary mechanical door-bell?*

By using a pull circuit-closer, like that shown in Figure 111, instead of a press-button.

As shown, the circuit-closer consists in a pair of springs, B B, mounted on a block of non-conducting material, like hard rubber, and connected respectively with the bell and battery wires, but not touching one another when in a state of rest. A hole is bored through the insulating block, and a rod ending at the inside in a metal disc, C, and surrounded by a helical spring, is passed through, and fitted at its outside end with the flange and knob, P. The helical spring serves to keep the disc, C, away from the ends of the flat contact-springs, B, and also to draw in the knob after it is pulled out to close the circuit. When the knob is pulled the helical spring is compressed, and the disc, C, makes contact with both of the flat springs, B, thus closing the circuit. The pull circuit-closer is well adapted for use in connection with door-bells.

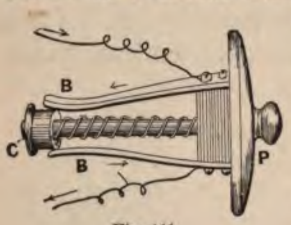

Fig. 111.

252. *How may we arrange a circuit to ring a single bell from two or more separate points?*

Such an arrangement may be easily understood by reference to the engraving, Figure 112. Setting up the bell and battery as before, connect one pole of the battery with one of the bell binding-screws by a wire; then run a wire from the other battery pole past and near to all the press-buttons, at the points from which it is desired to ring, terminating at the most distant press-button, to which the end of the wire, after being bared, is attached. At each of the intermediate buttons branch wires are extended from this battery wire in the following manner: At the nearest point of the battery wire to each of the buttons strip its covering from it for a ace of about an inch, and scrape the wire thus bared till it is bright; the wire at these points then presents the appearance indicated at A, Figure 114. Then bare about three inches of the ends of the proper number of branch wires, and wind the bared ends round the stripped portions of the battery wire, as at B, Figure 114; this, especially if soldered, makes a good splice. The free ends of the branch wires, after being bared, are attached each to one screw of their respective press-buttons, which may be at any distance from the main battery wire. In some cases two of the buttons may be very near together; the branch may then be connected to the main line in the manner represented in Figure 113; *c* being the main wire, *d* the branch to one of the buttons, and *e* the branch to the other. At this point in construction we have a battery wire extending by branches to each press-button. Finally, as in the figure, a simi-

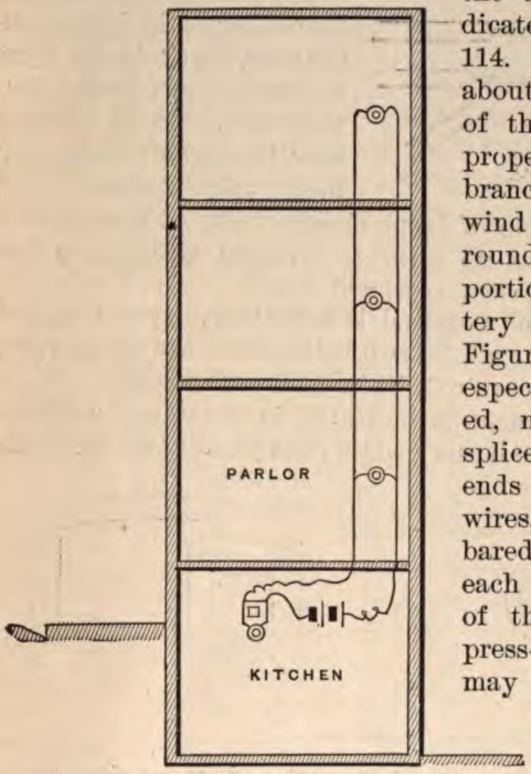

Fig. 112.

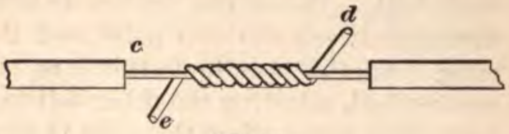

Fig. 113.

lar main wire is run from the remaining bell terminal to the most distant button, branching to the intermediate ones, precisely the same way as is done in the battery wire. It is obvious now that a bell circuit normally open is constructed, which is capable of being closed at any of the buttons.

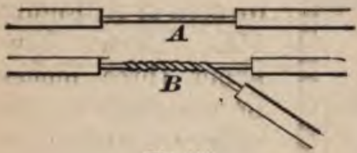

Fig. 114.

253. *How must the wires be arranged to ring two bells from a single button or circuit-closer?*

The apparatus required is a battery, a press or pull button, or key, and the two bells which are to be rung. These may, if required, be in different rooms.

The arrangement is indicated in diagram by Figure 115. One of the battery wires runs directly to one of the press-button screws, and the other battery wire is extended to one binding-screw of each of the bells, as shown. A third wire is led from the other push-button screw, and branches to the remaining binding-screw of each bell. When the button is pressed the current divides between the two bells, and thus they are both rung. Another way to do this is to provide but one vibrating bell, allowing the other bell to be a single-stroke bell; they must, when this plan is adopted, be arranged in series, or directly after one another in circuit, and the second, although in itself a single-stroke bell, will vibrate in unison or harmony with the intermissions of the current produced by the vibrator. In either of the

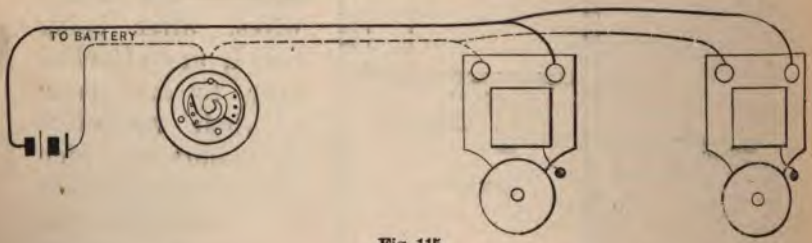

Fig. 115.

above ways several bells may be operated from one button or circuit-closer with one battery.

254. *Describe a plan whereby an answering press-button may be combined with each of a series of bells, so that a responsive ring may be sent.*

Such a device is shown by the diagram in Figure 116. The same battery is made to serve for the ringing in both directions. One pole of the battery, B, has a wire leading past all the bells, *b*, to the most distant one, branching to one terminal of each bell in passing. Call this wire No. 1.

From the other pole of the battery a wire is led which branches in two directions. One branch leads to a press-button, P, the other to the response bell, R. From the other screw of the press-button a wire, 2, is led to the most distant bell, branching to each bell *en route* in the same manner as No. 1. Now run a third wire, No. 3, from the remaining terminal of the response bell, R, to a point near to the most distant bell, *b*, there connecting it to one screw of the answering button, P, the other screw of the same button being connected by a short wire to main wire, No. 1. In like manner from No. 1, near each of the bells, *b*, short

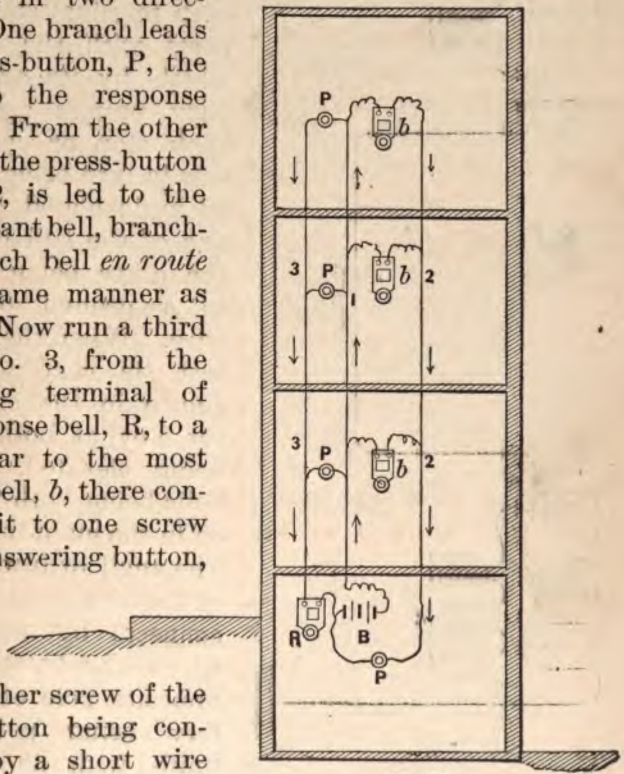

Fig. 116.

wires are run to the answering buttons, P, which by their other screws are connected with the response wire, No. 3. By this arrangement a pressure of the button, P, will simultaneously ring all of the bells, *b;* and when any of the buttons, P, are pressed, the bell, R, will be rung.

255. *Describe the circuit connections of a bell line of two stations, each of the said stations being capable of signalling the other.*

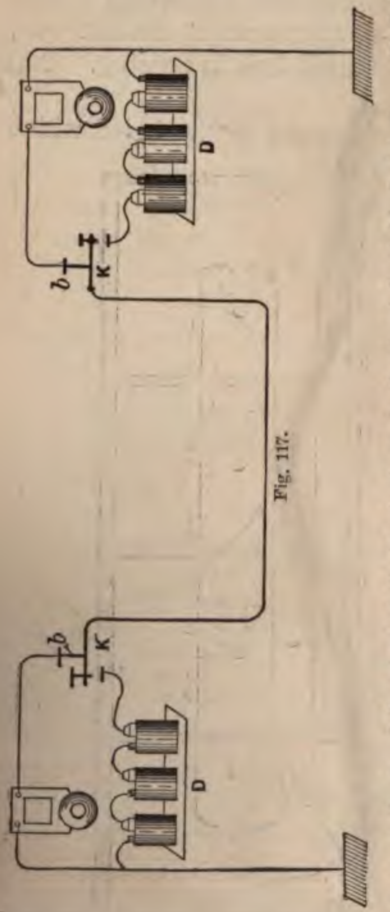

Fig. 117.

This arrangement will be understood by reference to Figure 117. The line at each terminal station connects with the key, K, which by its own resiliency presses against its back stop or contact, *b*, this in turn being connected by insulated wire with one of the bell terminals, the other being attached to a ground or return wire. When the line is at rest its condition is as shown in the engraving; the key at both stations being elevated, and the bells being both maintained in the main-line circuit. The anvil or front contact of the key at each station connects by means of a wire with a battery, D, the opposite pole of the battery being permanently united with the ground or return wire. When either key is pressed the distant bell will be rung.

256. *What kind of bell signals are or have been employed on telephone lines?*

A great variety have from time to time been employed. Small, single-stroke bells were at first much used, and in their operation a steady battery was kept on the line, and the signals were given by breaking and closing the circuit a given number of times. Magneto-bells are more universally employed at present than any other, because they are much cleaner, more economical in the end, more easily managed, and very rarely get out of order.

257. *What is a magneto-bell?*

A magneto-bell is a polarized relay, having its armature extended into a hammer which vibrates between two bells.

It takes its name from the fact of its being operated by the electric pulsations produced by the rotation of coils of wire across the field of force of a magnet.

258. *What is an individual signal-bell?*

Described in general terms, it is a bell which, when placed in series with other bells in an electric circuit, is so arranged as to ring when desired, to the exclusion of the others. That is, if, for example, six stations were placed on one circuit, any one of the six may be signalled without ringing the remainder of the bells in the circuit. These bells are usually adapted to be rung exclusively from the central station; but some varieties are capable of ringing any station from any other station.

259. *Upon what principle are individual signals constructed?*

Many different principles of action are embodied in these bells. A large number of them are operated by successive pulsations of electricity, which, when sent over the line, work a ratchet-wheel, either positively or by controlling the escapement of a clock-train. This ratchet-wheel, at a certain definite time or place, differing at each station, either brings into activity an extra electro-magnet, which works the bell-hammer, or al-

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lows the bell-hammer to reach the bell at the required station; the bells at the other stations having their electro-magnets cut out of circuit or their hammers mechanically controlled. When brought to the ringing-point, bells of the step-by-step class are frequently caused to ring by sending a current of different character from that used to work the step-by-step motion. Other kinds of individual signals are worked by a clock-train, which at definite times introduces the different magneto-bell magnets into the circuit. In such apparatus the clock-work is tripped by an electric current sent from the central station, and rotates, bringing into circuit the different bells one after another. Still another kind is the harmonic; these have armatures poised or tuned differently at each station in circuit. A transmitting instrument is placed at the central station, and provided with a circuit-breaker. The armature of the transmitter is adjustable in length, and when set in motion, only that circuit bell which corresponds in its rate of vibration to the rate of vibration of the circuit-breaker will ring.

CHAPTER XXI.

THE TELEPHONE.

260. *What is the electric telephone?*

The idea expressed in the word *telephone* is the transmission of sound to a distance, and hence any instrument capable of such transmission is properly termed a telephone. The electric telephone, however, does *not* actually transmit sound, but is simply an instrument by which, through the agency of electricity and a conducting medium therefor, sounds of any kind, including articulate speech, when produced at any point or place, may be simultaneously reproduced at any other place at a distance therefrom.

261. *What is the magneto-telephone?*

It is a telephone in which, when used as a transmitter, the vibrations of a metallic diaphragm, when sounds are uttered in its vicinity, cause variations of intensity in the field of force of a magnet, whereby electrical currents corresponding in character and form to the original sounds are produced in a helix of insulated wire surrounding the pole or poles of the magnet; these traverse a line-wire in the circuit of which the helix is included; and in which, when used as a receiver, the said currents circulating in the helix vary the strength of the magnet, which consequently attracts its diaphragm with varying strength, permitting it in turn to vibrate, and, by the movement in the air so caused, to reproduce similar sounds to those transmitted. The magneto-telephone is now used almost exclusively as a receiver, since it has been long known that battery telephones are much more powerful transmitters. It consists of a magnet, which may be either an electro or a permanent magnet. On one end of this magnet, or of a soft-iron core affixed thereto, is placed a coil or helix of fine, silk-covered wire, while stretched immediately in front of this core and coil is an elastic disc or diaphragm of thin sheet-iron, held to its frame by being compressed at its edges between the case and its cap or ear-piece. Some of the lines of force of the magnet pass through the coil, and others through the iron disc. Thus the plate is attracted towards the magnet with a constant force when the instrument is quiescent. When, however, a constantly varying electric current is passed through the coil, in either direction, the strength of the magnet is momentarily either increased or diminished, the attraction between it and the diaphragm varying accordingly. When the current in the coils is in such a direction as to reinforce the magnet the diaphragm is attracted more strongly than before, while if it is in the opposite direction it is attracted less strongly. Now, as these variations in the strength of the current are controlled by the action of the distant transmitter, they are in exact accordance with the movements of its diaphragm, and thus the diaphragm of the receiving telephone is caused to vibrate also in accordance with the transmitter, and reproduces the sound.

262. *Can the magneto-telephone, just described, transmit articulate speech, or is it restricted to its reproduction?*

It transmits speech quite distinctly ; indeed, for some time after its invention it was used for this purpose quite as much as for a receiver. It is one of the distinctive features of the magneto-telephone that it may be so used. When acting as a transmitting telephone the operation of the instrument, depending upon the principles of magneto-electric induction, is as follows: The voice of the speaker throws the air into vibrations ; these, acting on the diaphragm, cause it also to vibrate ; every vibration of the diaphragm alters the magnetism of the inducing magnet, and at every change in the magnetic strength a transitory current is produced in the coil. Since the coil is in the line circuit, these transitory currents pass over the line and through the distant coil also. There they affect the magnetism of the receiving instrument in a similar way; and the diaphragm of the said receiving instrument, being thus attracted with varying degrees of strength, repeats or reproduces the motions of the transmitting diaphragm, and the speech uttered in the mouth-piece of the sending telephone is thus duplicated by the receiver.

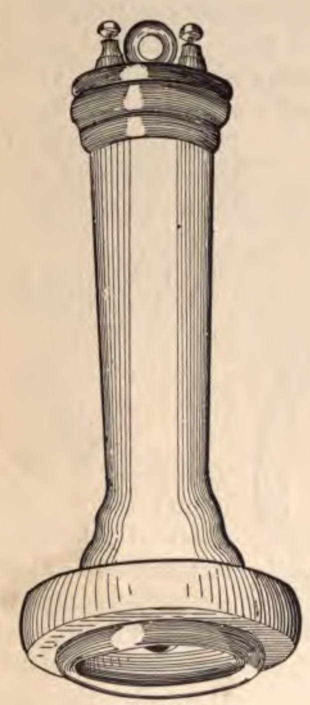

Fig. 118.

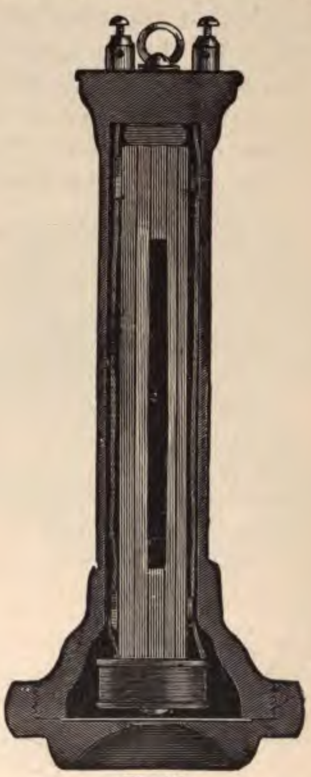

Fig. 119.

263. *Is the magneto-telephone restricted to any particular form?*

No; it may and has been made in many forms. The standard form, which is that adopted by the American Bell Telephone Company, is shown in Figure 118, while Figure 119 is a vertical section of the same, showing the internal construction. It consists of a case of ebonite or hard rubber, containing a compound bar-magnet made of four separate bars of steel (each one separately magnetized), laid together in pairs with similar poles together. By this construction it is found that the magnetism is more permanent than if a single bar were used.

At each end, between the two pairs, is placed a soft-iron core or pole-piece. The shorter one is placed at the end intended for the handle, and a screw passes into it from the outside of the case and aids in holding the parts together; the longer pole piece is placed at the diaphragm end.

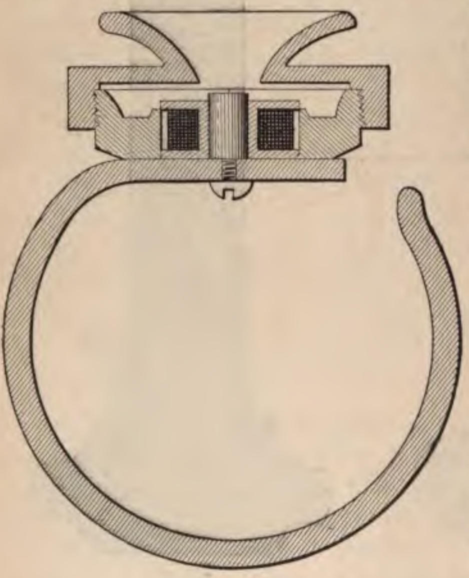

Fig. 120.

The helix, which is formed of very fine silk-covered wire, surrounds this longer core, and ordinarily has a resistance of about seventy-five ohms; its terminal wires are extended through the case beside the magnet, and are soldered to two binding-screws at the end of the handle. Stretched in front of the pole-piece is the diaphragm, which is simply a thin, round iron plate, such as is used by photographers in the preparation of ferrotypes. This is clamped at its edges between the end of the case and the cap which forms the ear-piece, and is thus maintained in close proximity to the magnet-core, which, however, it is never allowed to touch. This instrument is almost universally used in America. Another form which has been used considerably is that of the "Pony Crown," of which Figure 120 shows a sectional, and Figure 121 a perspective, view.

The "Crown Telephone," represented in perspective by Figure 122, has also been used to some extent.

The telephone designed by M. Clement Ader is one of the handsomest forms, and is used in France. It is shown in sectional elevation in Figure 123, while Figure 124 is a plan view of the magnetic cores and helices, with their enclosing cup, the diaphragm being removed, and Figure 125 a side elevation of the instrument.

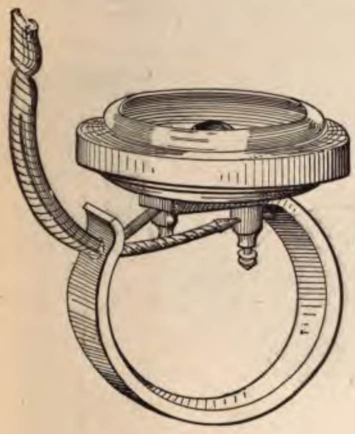

Fig. 121.

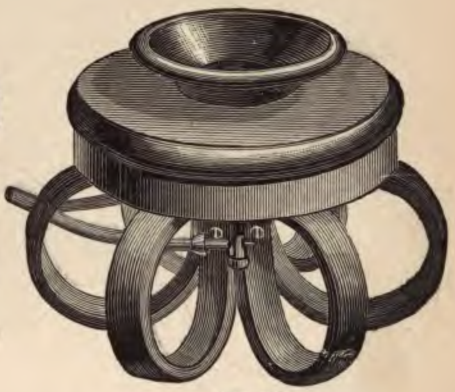

Fig. 122.

In this telephone A is the magnet, which is made circular. The pole-pieces are of rectangular form, and are surrounded by small helices or spools, B B, which in practice are connected with the binding-screws, N N, and by their means included in the line circuit. A cup of non-magnetic metal, O, is fastened to the magnet, and surrounds both helices, forming an interior space, across which, and passing close over the cores, is the diaphragm, M. A cap, C, fitted with a flaring ear-piece, E, surmounts the instrument. The peculiar feature of the Ader telephone is what the inventor calls a reinforcer. This is a mass of iron, X, enclosed in the cap, C, and lying within the field of force of the magnet, A, and said to aid and reinforce the magnet in its action on the diaphragm, and thus to cause the diaphragm to vibrate more energetically than it otherwise would, and to give out louder articulations. Very satisfactory results have been obtained from this instrument.

It is useless to attempt a description of the numberless forms of magneto-telephones which have been produced, the instrument being apparently capable of indefinite variation in form, but of very little variation in principle.

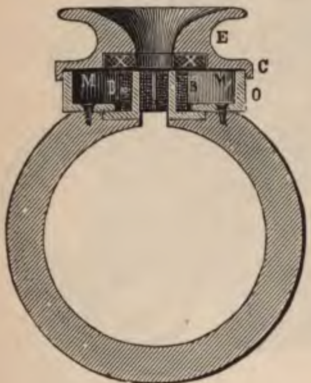

Fig. 123.

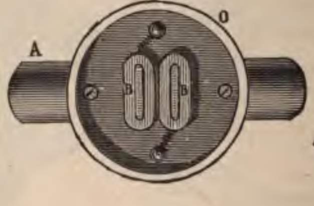

Fig 124.

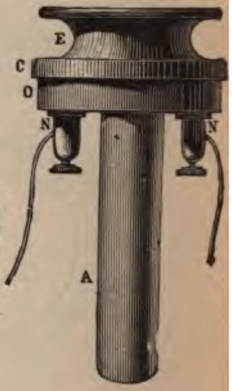

Fig. 125.

264. *What is a battery telephone transmitter?*

It is an instrument adapted for the transmission of articulate speech, in which the operating electrical currents, instead of being actually produced by the vibrations of a diaphragm in proximity to a magnet, as are those of the magneto-telephone, are developed by a voltaic battery, and the vibrations of the diaphragm under the influence of the voice operate merely to control the currents so produced. Battery telephones have been commonly arranged in two classes—viz., those like the typical Edison telephone, in which varying degrees of pressure are brought to bear upon certain semi-conducting substances included in the battery circuit, whereby the particles of such substances are brought into varying degrees of intimacy, their resistance varying in a corresponding degree and in proportion to the amount of pressure to which they are subjected; and those which are also technically and popularly called microphones, in which two points or electrodes of the circuit are brought more or less closely together in such a manner that the slightest shake or vibration greatly affects the amount of the resistance at the point of contact, and thus, of course, throughout the circuit.

265. *How do such instruments operate when used to transmit articulate speech?*

In those of the former type a diaphragm is mounted in a frame, just as in the Bell telephone, and is arranged to press with a light but steady initial pressure against a little button of prepared carbon or lampblack which is placed in the circuit. The resistance of finely-divided carbon has been by some supposed to diminish greatly under pressure; but the real cause of the apparent diminution is now thought to be, as before indicated, the closer intimacy into which the finely-divided particles are brought. However that may be, when the diaphragm is spoken against it vibrates, and presses with varying degrees of strength against the lampblack button, causing its resistance correspondingly to vary; and as the electro-motive force is supposed to be constant, the strength of the current in the circuit varies inversely with the resistance of the button. When the resistance of the button is greatest the strength of current is least, and when the resistance of the button is at its minimum the current strength is at its greatest. The best authorities no longer think that in the transmitter the resistance of the substance of the carbon is susceptible of variation, but believe that such variation is due, as we have already stated, to the varying degree of contact between the multitude of particles composing the mass.

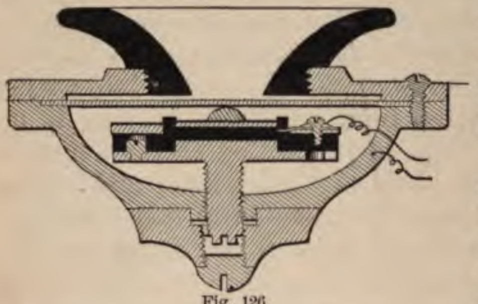

Fig. 126.

The Edison transmitter, which is the best-known instrument of the foregoing class, is shown in Figures 126, 127, and 128; Figure 126 being a vertical section of the transmitter, Figure 127 a perspective view, and Figure 128 a view of the entire instrument mounted on a jointed arm and fitted on a desk-stand, with bell-call, and automatic switch operating by the removal and replacement of the receiving telephone to change the line from its normal route through the signal-bell to the branch leading through the telephone.

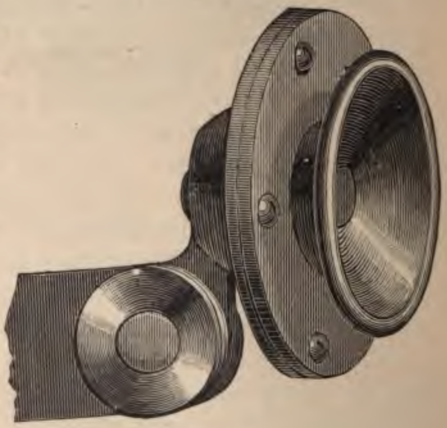

Fig. 127.

Figures 127 and 128 require no explanation. In Figure 126, which shows the transmitter in section, the button of prepared carbon is compressed between two metal surfaces, and the initial pressure is given by a screw, which is capable of adjustment from the rear. The diaphragm presses upon a protuberance of the upper metal plate, and when spoken against varies the contact between the metal plates and the button. One of the circuit-wires is attached to the upper metal plate, and the other to the metal casing.

The well-known Blake transmitter may be taken as the type of the second variety. Figure 129 represents the external appearance of this instrument as usually constructed.

The operative parts consist of a diaphragm loosely supported in a frame and clamped thereto, while suspended from one of its edges are two flat springs; the nearest one to the diaphragm is the lightest of the two, and at its extremity carries a little stud of platinum, which at one side touches the diaphragm, and at the other a little disc of hard carbon with a highly polished face; the carbon disc is carried on the lower end of the other and heavier spring. The two springs are relatively so adjusted that when they both from any reason are forced

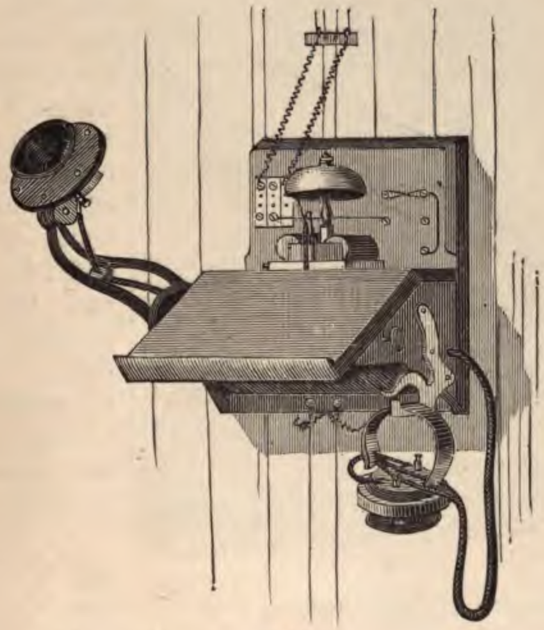

Fig. 128.

away from the diaphragm, the platinum point has a tendency to follow the carbon disc for at least a short distance, usually about three-eighths of an inch.

The springs are insulated from one another, and the only connection between them is at the point of contact between the platinum and the carbon.

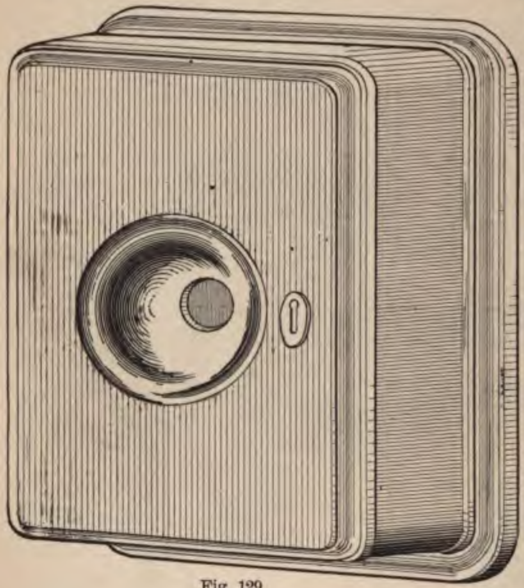

Fig 129

Figure 130 shows a sectional elevation of the working parts of the transmitter. The two springs are carried upon the same adjusting lever, F, this being suspended from the frame, B, by a stiff flat spring, and being adjustable by the screw, G. This adjustment regulates the initial pressure of the carbon and platinum electrode, and also the pressure of both against the diaphragm, D.

Figure 131 is a representation of the instrument with the door open and all parts in their proper position. The diaphragm, which is insulated from the iron frame by an encircling band of india-rubber, is on one side clamped to its frame by the brass clamp, *h*, and is at the other furnished with a damping spring, K, by which undue vibrations are checked.

The front of the case is fitted with a mouth-piece; and in one corner of the case, as shown in Figure 131, the induction-coil stands. Connections are arranged whereby the two springs and the electrodes they carry, together with the primary circuit of the induction-coil, are placed in a battery circuit. These circuit connections are represented in Figure 132. A, B, C, and D are binding screws, A and B for the battery-wires and C and D for the line-wires. Entering at A, the circuit of the battery proceeds by the wire S to the hinge H, and by the wire M to the platinum electrode through the spring, I; from thence it continues to the carbon button, J, and by the spring thereof to the metal adjusting-lever, K, and by means of the screw, O, to the frame, V. A wire, L, unites this frame to the lower hinge, G, and from thence another wire, P, leads to the primary coil, F, and out to the battery return by wire Y and screw B. The line-wires, or line and ground wires, are simply attached to the binding-screws C and D, which by the wires X and W lead through the secondary coil, E. In this diagram N represents the diaphragm. When in the operation of this transmitter the diaphragm is spoken to, the contact resistance of the platinum and carbon electrodes is varied, and the resistance of the circuit, and the strength of the current flowing therein, are correspondingly varied.

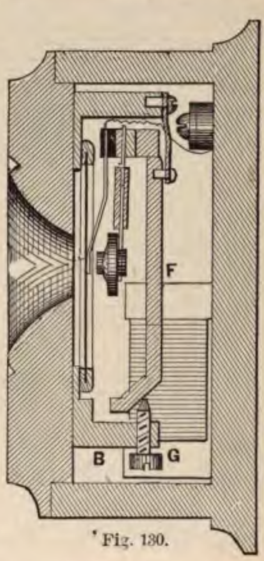

Fig. 130.

The essential difference between the action of the battery and magneto telephones, when the latter is used as a transmitter, is that in the battery transmitter the electrical undulations are produced by varying the resistance, and in the magneto by varying the electro-motive force.

266. *What is the reason that an induction-coil is used in connection with battery transmitters?*

It is found to be an advantage to use an induction-coil, and to place the microphonic contact, or the variable resistance, in its primary circuit, connecting the terminals of the secondary circuit of the coil with and in the line circuit, because although the said resistance is capable of, and actually passes through, great variations when actuated by the vibrations of the diaphragm, the extreme variation between the highest and lowest points is but an inconsiderable factor in a long-line circuit, whereas the same variation in a short local circuit is proportionately great. Therefore by placing the

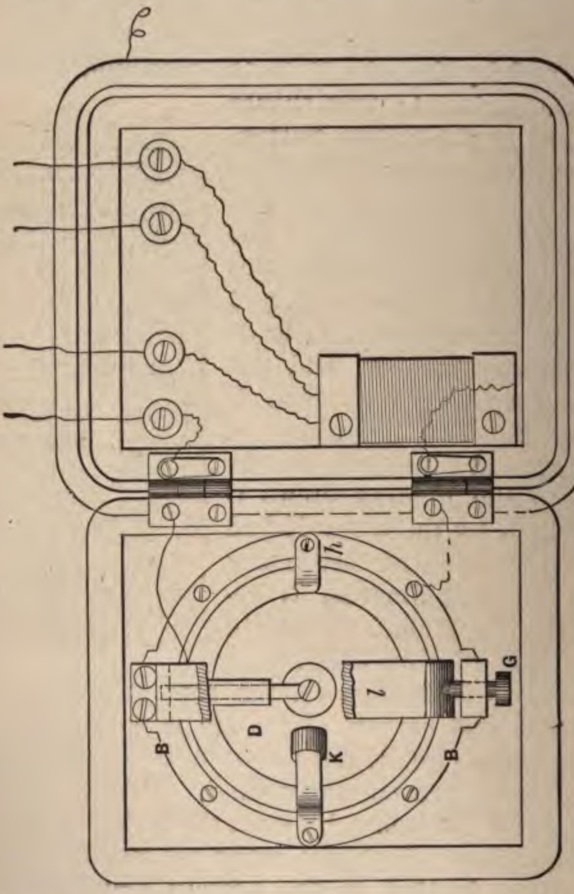

Fig. 131.

variable resistance in the short circuit of a primary coil, where a comparatively small change in the total resistance in the circuit would cause a great difference in the strength of current; and by causing the secondary coil to be a part of the line circuit, we produce in the secondary coil, and hence in the line of which it forms a part, induced currents, having as wide a range of variation in the line circuit which they traverse as the battery currents which induce them have in the primary coil and circuit; and they thus act with equal vigor upon the diaphragms of all receiving telephones in the main circuit, irrespective of the varying distances at which they may be placed.

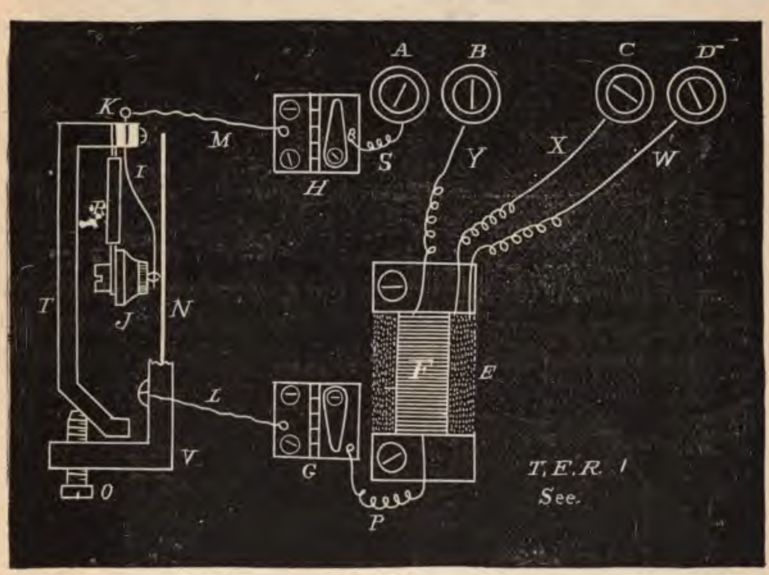

Fig. 132.

267. *What other types of transmitting telephone are used?*

There are but two other forms of transmitter that have been employed to any extent. These will be now described.

The first is the Crossley transmitter, which is represented by Figure 133, and consists of a number of variable contacts, which may be partly in series and partly in multiple arc. As usually constructed, these contacts are produced by arranging on a wooden diaphragm, which may or may not be furnished on the reverse side with a mouth-piece, a compound microphone, consisting of four carbon pencils resting loosely at their ends in carbon socket-blocks of the form shown. The circuit-wires are attached to two of the opposing socket-blocks,

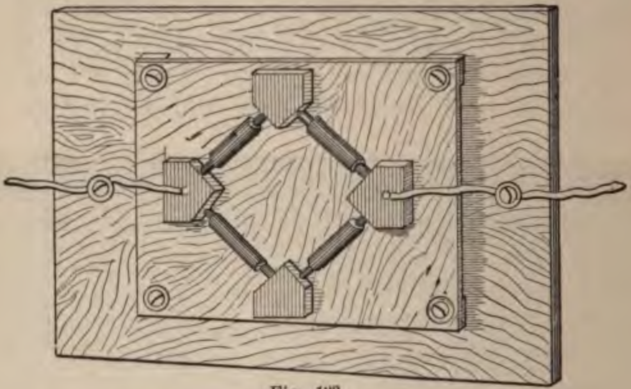

Fig. 132.

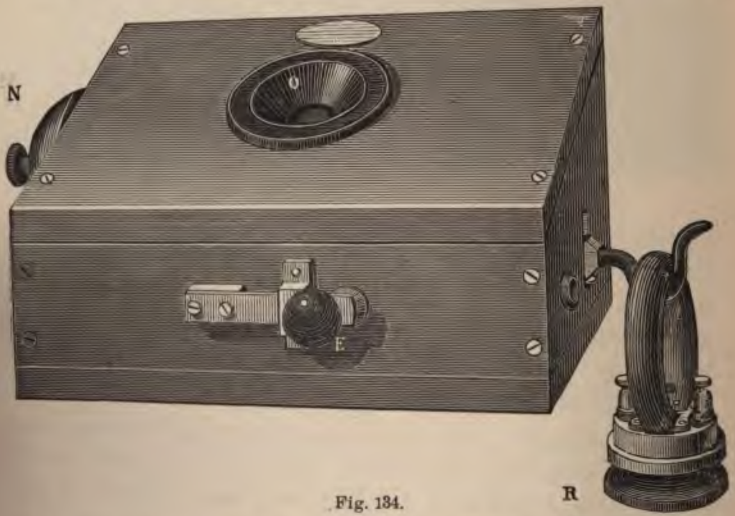

Fig. 134.

The microphone in practice is worked with a battery and fitted with an induction-coil, precisely as in the Blake and Edison transmitters. The entire apparatus is set up for work in the form represented in Figure 134.

The apparatus is mainly enclosed in a compact box, on which is fixed the call-bell, N, a calling-key, E, being placed on the front of the box, and the usual automatic switch, adapted to operate as a rest for the telephone, at the end opposite to the bell.

The second form is one wherein suitable conducting material in a finely-divided condition or in the form of a coarse powder is enclosed between two conducting surfaces in a battery circuit, the strength of current being varied by the change of position in the particles of the powder. The principal type of this instrument is that invented by the Rev. Henry Hunnings, and of which Figure 135 is a representation. A metal plate, B, of any desired thickness, is placed in a recess cut into a suitable block, D, and connected with a binding-screw terminal, E; stretched over this, and held in place by a ring, F, or in other suitable way, is a very thin diaphragm of metal, A (platinum foil is generally used), which is arranged at such a distance from the first plate as to form a shallow intervening space. The thin diaphragm is connected with the second binding-screw, and the intervening space is nearly filled with loose, finely-divided conducting material, C, oven-made coke being found to

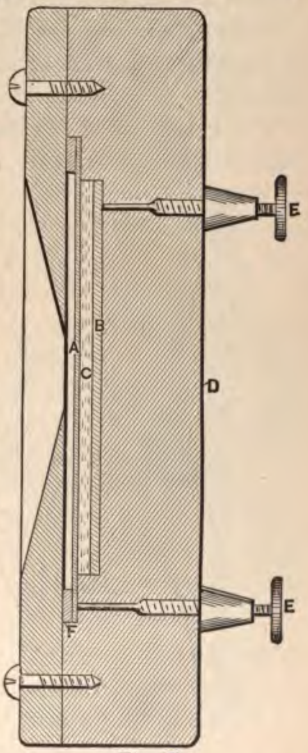

Fig. 135.

give good results. The instrument, when in use, may be connected directly in the line circuit, a battery also being included therein, its great initial resistance rendering the use of an induction-coil unnecessary. Of course this transmitter is not restricted to any special form. In practice a suitable handle is usually added for convenience. Both Crossley's and Hunnings' transmitters, though differing materially in detail from one another and from transmitters of the Blake and Edison types, yet operate on the broad principle of varying the strength of a battery current by varying the resistance of the circuit at one or more points in the said circuit.

268. *What is Dolbear's receiving telephone?*

It is a receiver in which the vibrating plate is operated by the variation of a static charge of electricity instead of by the variation of magnetism produced by a varying current.

The instrument in its simplest form is shown in section in the figure, and consists of two metallic discs, C and D, about two inches in diameter, so mounted as not to be in metallic contact. This is effected by separating them at the edges by a flange of hard rubber, which forms a part of the enclosing case. The mouth-piece is screwed down over one of the plates, and a handle over the other. Through the middle of the handle a screw is sunk, which touches the back plate and serves to adjust its flexibility. The back plate is thus fastened both at the middle and at the edges, and therefore cannot vibrate, while the front plate, being fastened only at the edge, is free to vibrate.

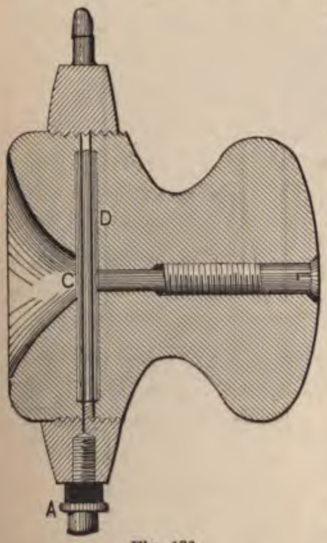

Fig. 136.

A screw-post, A, is attached to each plate, by which the instrument may be attached to the line-wires or to the line and ground. It is quite feasible, however, to connect but one of the plates to a binding-screw terminal, for attachment to the line-wire only, and to unite the other plate to a metal ring or plate on the knob which must be touched by the person using the instrument. A large induction-coil is essential in connection with the transmitter when this receiver is used, and any microphonic transmitter will answer.

269. Why is it usual to place the receiving telephone, when not in use, upon a hook or yoke at the end of a lever-switch?

Upon the introduction of the telephone as an instrument of electrical communication it was found that it could not be depended upon to speak loud enough to announce when a message was to be sent, and thus it became requisite to place at each station an electric bell, by means of which a signal might be given from the distant station whenever it became desirable to attract attention. It was also found to be advantageous for many reasons to keep the telephone helices out of the line circuit, except during the act of conversation. A switch which should be able at any desired moment to cut the bell-magnet out from the line, and introduce the telephone into the line circuit, and *vice versa*, thus became an essential. A button-switch was first used for this purpose, but the attendant or user frequently forgot to replace the switch, so as to restore the signal-bell to the circuit when conversation was finished. This led to the device of a lever-switch which should be operated by the weight of the telephone; and the fact that when the telephone was laid down the hook or yoke was the most natural place for any one to leave it, was relied upon to furnish a constant and sufficient reminder for persons so to place it, and thus make the required circuit change automatically, or without any positive act of their own being necessary.

270. *How is the automatic switch generally constructed?*

A bar of metal, terminating at one end in a hook or yoke adapted for the support of a telephone, is pivoted in the bell-box, so that the end for the telephone support projects some distance on the outside through a slot. This bar is permanently attached to the line-wire, and when the weight of the telephone is on the bar it is brought into contact with a flat metal spring which is united by a wire to the bell-magnet, and thence to earth. When the weight is taken from the end of the bar the outer end of the bar is drawn upward by a spring, and makes contact with another spring united with a wire leading to the telephones, and thence to the earth. The connections are shown in the diagram, Figure 137.

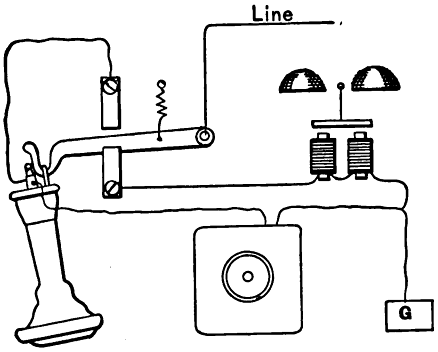

Fig. 137.

271. *In an ordinary magneto-bell box what other office is ordinarily performed by the automatic switch?*

Since the general introduction of the battery transmitter, in addition to the work of transferring the main-line connection from the signal-bell to the telephone branch, the automatic switch-lever is so arranged as to close the local battery circuit of the transmitter when the telephone

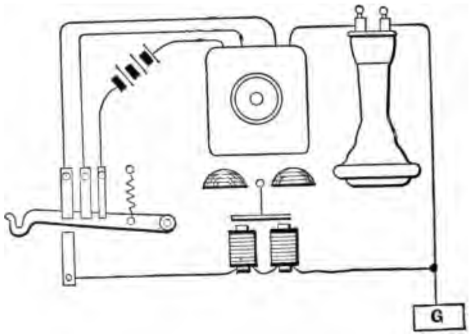

Fig. 138.

is taken from its support. Owing to the general use of open-circuit batteries for this work such a contrivance is necessary. For convenience and compactness the battery circuit is led into the bell-box, and terminates therein in two flat springs, which, when the telephone rests upon its lever, have no communication with one another. Leaving the carbon pole of the battery, a wire may be led to the transmitter; there the circuit is through the contact points and the primary circuit of the induction-coil; from the transmitter it goes to the bell-box to one of the flat springs, while a wire from the other spring connects with the other pole of the battery. The act of removing the telephone from its place of rest, and the consequent recoil of the switch-lever, is made to interpose a metallic connecting piece between the two flat springs, and so the circuit is closed.

CHAPTER XXII.

ELECTRO-THERAPEUTICS.

272. What is meant by the compound term "electro-physiology"?

Electro-physiology is that branch of electrical science which treats of animal electricity and its laws; and also of the phenomena produced by the action of electricity upon the skin, muscles, and other organs of living beings when in a natural or healthy condition.

273. What effects may be produced in the body by the application of electricity?

When a current from a battery of considerable electro-motive force is passed through the human body it produces a disagreeable tingling or burning sensation at the points at which it enters and leaves the body. A sudden and strong current of short duration, such as would be produced by the discharge of a Leyden jar, when sent through the body, produces what is generally known as an *electric shock.* The disturbance caused in the animal system by such shocks can be made so great as to produce severe illness, or even death. Deaths by lightning are due sometimes to the sudden discharge of electricity *from* the body, which has been inductively charged by the clouds, and sometimes to the direct stroke.

The passage through the body of a rapid succession of magneto-currents, or of currents from an induction-coil, produces a species of temporary paralysis or numbness, so that a person grasping the electrodes connected with a source of electricity cannot let them go, but is constrained to convulsively hold them until the cessation of the currents.

That many modifications may be made in the condition of an animal body by electricity is very evident from the contraction of muscles and nerves when subjected to its action; and also from the fact that the fluids of the body are all compounds of several elements, and hence are all capable of electrolysis.

274. *What is the meaning of the words therapeutics and electro-therapeutics?*

Therapeutics is the name of the science of healing. Electro-therapeutics is the branch of electrical science that treats of the study of electricity in its relation to disease and as applied to the healing or alleviation of disease. It is a very old idea; indeed, the remedial powers of electricity are referred to by Pliny. Only quite recently, however, has it advanced to the dignity of a science, and its practical history may be traced from the year 1743, when Krüger d'Helmstadt suggested that frictional electricity might be made serviceable in the practice of medicine. From that time until the discovery of the voltaic battery, fifty-six years later, frictional electricity was considerably used as a remedial agent, with varying success. In 1799 the voltaic battery was first constructed. This gave new life to electro-therapeutics, and rapidly superseded the use of frictional electricity; and voltaic currents yet subserve valuable purposes in this department, and are extending their usefulness continually. Another advance was made in 1832, when Neef, of Frankfort, commenced to use the rapidly alternating currents of magneto-electricity in the treatment of diseases. For a long time, however, electrical treatment was regarded as a species of quackery, but is now fully recognized as a valuable element in the healing art.

Both battery and magneto currents are at the present time extensively employed in electro-therapeutics.

275. *What are the names applied by the medical profession to the three forms of electricity we have referred to?*

The first, frictional electricity, is often denominated

Franklinic, because of the large share borne by Franklin in its application to medicine. The second form is generally called *Galvanic*, and its application is called "electrization by galvanization," because Galvani, the Italian physician, by his researches brought the subject prominently before the scientific world, which publicity resulted in the conception and construction of the battery by Volta. The third form is by the medical profession called *Faradic* electricity, because Faraday was the discoverer of magneto-currents and the method of producing them.

276. *What instrumentalities are principally employed in electro-therapeutical applications?*

The direct current of a battery is sometimes employed through the intervention of a coil, which is composed of wire varying in thickness at different parts of its length, and furnished with a switch, by which more or less of the coil may be placed in circuit; a circuit-breaker is also provided, by which, if desirable, a succession of shocks may be produced. Frequently a complete induction-coil is employed, in which case the electrodes of the secondary coil are applied to the patient. Magneto-electric machines are also extensively used for medical purposes, and are very convenient for the application of rapidly recurring pulsations of alternating direction.

277. *What is meant by electro-surgery?*

It is a branch of electro-therapeutics which exclusively treats of the application of electricity to such diseases which are commonly known as surgical. In addition to the ordinary methods of application by passing electricity through the body or portions of the body, it includes two other methods—*i.e.*, galvano-cautery and electrolysis, which two are peculiar to it.

Electro-surgery as a special branch dates back only as far as 1825, but is, perhaps, now the most valuable feature in the entire field of electro-therapeutics.

Galvano-cautery means the practice of burning or searing by a wire of high electrical resistance, heated by the passage of electricity through it. This method is often used in the removal of tumors and cancers. Electrolysis, which implies the art or process of decomposing a compound substance by electricity, is chiefly applied to the decomposition of morbid growths, or to organs affected by chronic inflammation, by means of some form of needle electrodes, which are inserted in the diseased part.

278. *What is the approximate electrical resistance of the human body?*

The resistance, in ohms, of the human body averages about as follows: From one hand to the other, through the body, hands dry, over ten thousand ohms; same with hands wet, six thousand ohms.

From mouth to hand, hands dry, eight thousand ohms; same with hands wet, five thousand ohms.

These results were deduced from measurements made of eight persons by Professor A. E. Dolbear, of Tufts College, Somerville, Mass.

279. *What is an electrical probe?*

The electrical explorer, or probe, is a little instrument employed to ascertain the presence and location of metallic bodies in wounds.

It is in shape much like the Edison electric pen, and consists of a slender rod or sound, which encloses two conducting wires or needles, insulated from one another, and covered entirely by a non-conducting substance.

The points are uncovered, and the other or outer end of the sound supports in a convenient stand a little vibrator, or trembling electro-magnet. One of the probe conductors is attached to the electro-magnet, and the other by a flexible cord to the battery direct; the other pole of the battery is connected with the second magnet-wire. When the circuit is closed by the contact of the two probe-points upon a metal surface—for example, a leaden bullet—the battery current traverses the magnet, causing the armature to tremble. The depth at which the bullet lies is simultaneously made known by the extent of insertion.

The first electric exploration of wounds occurred in 1863, and was conducted substantially upon the above principle; instead, however, of the vibrating magnet a galvanometer was used as an indicator.

CHAPTER XXIII.

OTHER APPLICATIONS OF ELECTRICITY:—ELECTRIC CLOCKS —TIME-BALLS—ALARMS—BLASTING—TRANSMISSION OF POWER—ELECTRICAL STORAGE.

280. *What are electric clocks?*

They are clocks which are either driven or controlled by electricity. In clocks which are driven by electricity the ordinary use of a spring or weight is dispensed with; and instead of using the pendulum to retard and regulate the motion, it is employed to propel the hands, being itself attracted alternately from side to side. The second class of electric clocks is that in which a clock of otherwise ordinary character, driven by weight, controls or governs by electricity a number of subordinate clocks.

A clock of the former class consists, usually, simply of a pair of hands adapted to rotate round a dial, and placed on the axis of a ratchet-wheel, which, by means of an electro-magnet, armature, and pawls, is caused to advance one tooth with every two swings of the pendulum.

Clocks of the second class, on the contrary, are generally constructed with a regular train of clock-work, the escapement of which is alternately released and retained by an electro-magnet, which is charged and discharged by the action of the controlling clock, which makes and breaks the circuit of the said electro-magnet.

281. *When and by whom were electric clocks of the first variety invented?*

The clock in which electricity supplies the actual motive power was first suggested by Alexander Bain in the year 1840. In the next year, 1841, he, in conjunction with a Mr. Barwise, obtained a patent for the application of electricity to the regulation and movement of clocks. The patent specified for its principal object the movement of several clocks by currents of electricity, transmitted at regular intervals by the agency of a clock of ordinary character, which, of course, indicates the second system we have spoken of; and it is probable that Mr. Bain would have succeeded better had he carried out that system. But by a subsequent improvement each clock was made to move independently by electricity, and this method was at that time regarded as a much more perfect invention.

The arrangement by which this is accomplished will be understood by reference to the annexed figure. The pendulum-bob, A, consists of a hollow coil of covered copper wire, and is suspended from the rod B, the wires, *e d*, from the ends of the coil, being carried up the pendulum-rod, and at the upper end thereof maintained in metallic connection with two springs from which the rod hangs. A brass tube, C, about two inches in diameter, passes through the coil, there being sufficient space left for the coil to move backward and forward without touching. Within this tube, and on each side of it, are placed permanent bar magnets, with their similar poles, *n n′*, presented towards one another at a distance of about four inches apart.

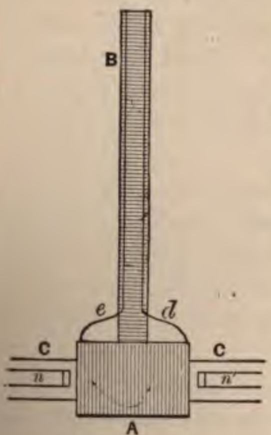

Fig. 139.

When an electric current passes through the coil, A, it instantly becomes magnetic; the end towards the right, we will suppose, having a south polarity, and that towards the left a north polarity. The coil is consequently attracted towards the right, and is repelled by the magnets on the left, as the pendulum swings in that direction.

Before arriving at the end of its vibration the connection with the battery is broken by the action of the pendulum; the magnetic property of the coil instantly ceases, and it descends by the force of gravity. On ascending the other arc of its vibration, contact is made with the battery, and a current is sent through the coil, but in the reverse direction; so that the left hand of the coil has south polarity given to it, and the right becomes the north pole. By this reversal of the current the coil is impelled towards the left, and the vibrations of the pendulum are thus maintained for an indefinite time. A light frame attached to the upper end of the pendulum-rod carries springs which connect with the coil-wires, *e d*, and make and break the battery contacts, and reverse the direction of the current through the coil.

Fig. 140 shows the mode in which the vibrations of the pendulum are made to propel the hands. An electro-magnet, A, is fixed on the top of the clock, and the current is sent through the coil on each vibration of the pendulum. Upon each electrical pulsation the magnet attracts the armature, B, to which the pawl, D, is attached, and this, engaging with the teeth of the ratchet-wheel, E, advances it one tooth. The wheel is prevented from falling back by the retaining pawl, L. By this arrangement the ratchet-wheel is advanced one tooth by two swings of the pendulum. Thus when the wheel contains thirty teeth, and the pendulum vibrates once a second, the wheel will make one complete revolution

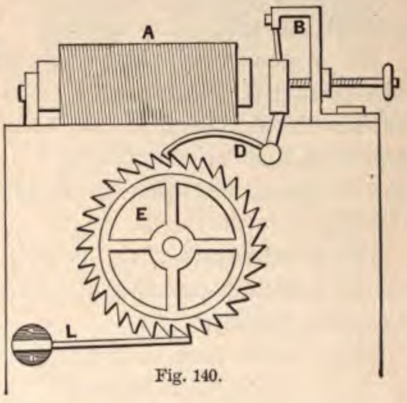

Fig. 140.

every minute. That wheel will, therefore, constitute the seconds-wheel of the clock, and the minute and hour hands may be moved by it in the same manner as in ordinary clocks.

Mr. Bain worked these clocks by means of an earth battery consisting of a large plate of zinc and a quantity of coke buried in moist ground. They did not work very satisfactorily, chiefly, no doubt, because of the unstable nature of the battery.

282. *How may clocks of the character described above be governed by a central clock, and by whom was such a method devised?*

As we have seen, Mr. Bain described such a system in his patent of 1841. Wheatstone, however, is generally regarded as the first person to conceive the idea of a number of clocks governed or controlled by a central clock. His ideas were greatly improved by Mr. R. L. Jones, an English railroad man, and Mr. Ritchie, of Edinburgh. Clocks operated upon this general plan have had considerable success, and are largely used in connection with observatories and many other large establishments.

Mr. Jones used clocks made on the Bain principle. The standard or governing clock is the only one provided with a circuit breaker or changer, and its pendulum is not under electrical control. In short, it is of the usual construction, except that it is made to operate a circuit-breaker.

The pendulums of the copying clocks have no break, as the primary pendulum performs the circuit-breaking function for all.

The clocks are, therefore, necessarily maintained together. The pendulums are not entrusted completely to the stimulus of the electricity, but are moved by their own we[illegible]at even if their supply of electricity should [illegible] would go on for a time without it. [illegible]flict between the two controlling forces [illegible] gravity, and by this system, therefore, copying clocks of little value may be made as perfect as the most costly observatory clock.

283. *How are clocks of the second variety to be operated, and by whom were they first arranged?*

As already indicated, these clocks may have a regular train of mechanism, and may be operated, as shown in the annexed figure, by an electro-magnetic escapement. One pendulum may serve any number of clocks. At each clock is an electro-magnet, B, the armature of which is a permanent bar magnet, N S, carrying an escapement, D, which works into an escapement-wheel, E, and thus either positively propels the clock or regulates its movements. The pendulum may be placed in one of the clocks, and by dropping its points, A, into the mercury-cups, *m′*, alternately, continually reverses the current of the battery, Z C, through the escapement magnet, B. Any number of these magnets may be worked in series by a proper proportionment of the battery.

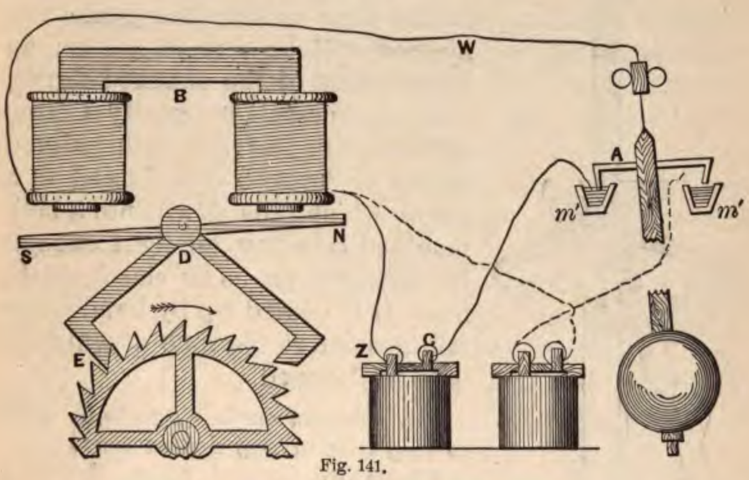

Fig. 141.

The first introduction of this principle into electric horology was made by a Mr. Shepherd, of London, who exhibited the arrangement publicly at the International Exhibition of 1851.

284. *How may time-balls and time-guns be operated?*

They are operated by being electrically connected with a clock which is arranged to complete a circuit by means of contact-springs, and thus at any predetermined time attract the armature of an electro-magnet and release a trigger, which permits the ball to drop or fires the gun. The method will be understood on an examination of the annexed figure, 142. A time-ball is usually a large wicker globe covered with painted canvas or flannel; this is fixed to a piston which falls down into a bell-mouthed tube just air-tight enough for the air to act as an elastic cushion. It is hauled up by hand a few minutes before the time at which it is to be dropped.

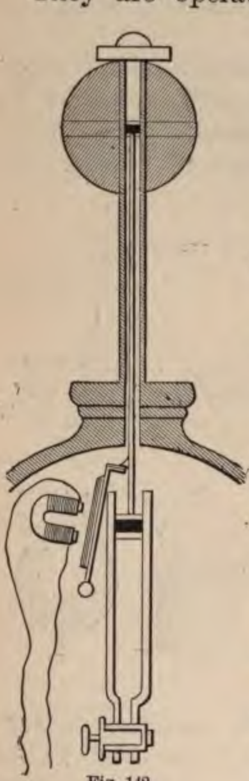
Fig. 142.

285. *How can ordinary clocks, be made to ring bells at any desired time?*

There are several ways of doing this. One of the easiest is to place on the arbor of the hour-hand a circuit-wheel of non-conducting material having a small piece of metal let in at one point of its periphery and extending through to the metal of the arbor, so as to be electrically connected with the frame and works of the clock.

The wheel is made to fit, by friction only, upon the arbor, and is just tight enough to prevent slipping, while it is sufficiently loose to be easily moved round for setting at any desired point. A flat spring is attached to an insulated base and made to press lightly on the edge of the circuit-wheel; it is connected with one pole of a battery. The metal part of the circuit-wheel, by means of the frame and clock-work and a connecting wire, is united to one binding-screw of the alarm-bell, and the other screw of the bell to the second pole of the battery. When, by the movement of the clock, the spring is brought into contact with the metal piece on the edge of the circuit-wheel, the circuit is closed and the bell rings until the metal has passed from under the spring. The wheel, being only attached to the arbor by friction, is easily readjusted.

Sometimes an arrangement like the above is unsatisfactory, because the wheel, being on the hour-hand arbor, rings the bell too long ; when such is the case a second circuit-closer is attached to the arbor of the minute-hand, which closes the battery circuit at that point once an hour. But as the circuit is also open on the hour-hand wheel, the bell cannot ring ; therefore only when both circuit-closers close at the same time can the bell ring, and only for the length of time that the wheel on the minute-hand arbor takes to pass its spring, which time can be made very short.

Another way is to insert one or more metal points in the face or dial of the clock, connecting all the points to one of the bell and battery wires, and then to arrange a trailing spring to travel round, attached by friction to the hour-hand arbor, and connected with the other battery wire ; a little switch is provided in each of the wires leading from the metal points to their main connecting wire, and the switch of the point at which the bell is desired to ring is closed.

286. *What are the principal methods of blasting by electricity?*

Passing a spark discharge, produced either from a frictional machine or a Ruhmkorff or Ritchie coil, through a fuse of fulminating powder, which in its deflagration kindles the larger charge of gunpowder or other explosive, is one very general method.

Another way frequently adopted is to arrange a fuse in which a very fine platinum wire is joined in circuit with a pair of stout conducting wires leading from a battery. This wire becomes heated when the current flows, and, being laid amidst an easily combustible substance, the latter is ignited and sets fire to the charge.

287. *Describe more particularly how frictional or high-tension electricity, such as that developed by the frictional machine or induction-coil, is used to explode charges.*

A fuse is made, consisting of a hollow rod of gutta-percha or some other suitable non-conductor, and in this are placed two insulated wires with their ends bared; one of these wires enters the non-conducting rod at one end, and the other wire enters the other end, so that their bared ends tend to meet one another. These ends are not permitted to touch, but remain a little distance apart; they are, however, connected by a layer of the fulminating material or mixture, which is preferably a composition of sub-sulphide of copper, sub-phosphide of copper, and chlorate of potash. A fuse has been employed which is based upon the action which india-rubber has upon copper. It has been ascertained that when copper wire is insulated with vulcanized india-rubber its surface becomes covered, after a lapse of some months, with a layer of sulphide of copper, which is capable of conducting electricity. The fuse is ingeniously formed by removing a portion of the covering from a loop of such wire, as in Figure 143, and then cutting away a very small piece of the wire.

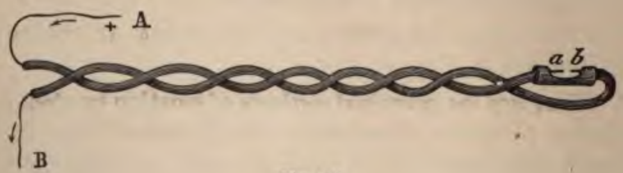

Fig. 143.

A and B represent the wires leading from the source of the electricity, and the current, interrupted by the space between the points *a* and *b*, takes the route by means of the sulphide of copper which coats the inner surface of the covering, igniting it, and with it any inflammable substance, like gunpowder or gun-cotton, which may be placed in the cavity.

If the exploding is done by an electric machine it is better to first charge a condenser by means of the machine, and then discharge the condenser through the fuse. In addition to the sources of electricity which have been already mentioned—*i.e.*, the electric machine and induction-coil—a magneto-electric machine is frequently used; while if the fuse employed is composed of the three ingredients first described it is quite possible to explode it even with a battery current.

288. ***Describe more particularly how electricity generated by a battery or dynamo-electric machine is used in blasting.***

The battery or dynamo-machine being provided, wires are led from its poles to the different points at which the explosions are to be produced. At these points the large wire, which is insulated, is cut, and a small piece of very fine platinum wire stretched between the two ends of the break. As many of these platinum joints as are desired are in this way placed in the circuit. The fuse is caused to surround the fine wire, which should be coated with fulminate of mercury. Upon closing the circuit of the battery or machine the fine wires are heated to redness by the passing electricity, and explode their charges.

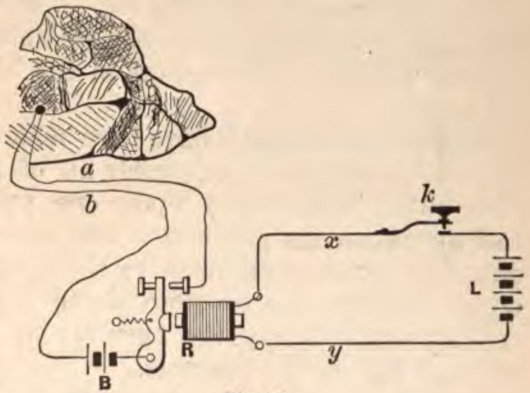

Fig. 144.

In the accompanying figure the circuits are represented as being arranged to operate the exploder from a safe distance. The fuse, being hidden in a hole drilled in the rocks, is connected by wires, *a b*, with a battery, B, the circuit of this battery passing also through the contact-points of the relay, R. The relay electro-magnet is in the circuit of the battery L, by means of the wires *x y*, and when the main circuit is closed by the depression of the key, *k*, the relay armature is attracted, the local points come together, the local circuit is closed, and the charge is fired. The battery B and relay, R, are, of course, placed in a protected position.

289. *What advantage has the second plan over the first?*

It has two advantages: first, that the condition of the conductors may be tested after they are laid, from time to time, as frequently as may be desirable, by feeble currents which will not heat the platinum wires to any great extent; and, second, that several insulated conductors may be laid in one cable without interfering with each other, which cannot be done when a fuse is fired from a condenser discharge, owing to the powerful currents induced in the adjacent wires, which would fire the fuses attached to all the wires whenever an electrical current or impulse was passed along a single wire.

290. *Has electricity been applied to the production of motion?*

Yes; the idea of a moving force derived from electricity, and especially through the medium of electro-magnetism, was one of the earliest in the history of electrical science.

Numberless attempts have been made to embody the idea in a practical form; nearly all of them, up to the year 1872, being based upon one principle—namely, the instantaneous production and destruction of force either by making and breaking the circuit of a battery which includes one or more electro magnets, or by reversing continuously the currents in the circuit and through the electro-magnets.

One of the earliest electro-motors of which we have any knowledge is that of Professor Jacobi, who in 1834, under the auspices of the Russian government, nstructed an electro-magnetic engine of considerable power. This was fitted in a boat 28 feet long, 7½ wide, and drawing 2¾ feet of water. The boat moved, when propelled by the engine, at a rate of four or five miles per hour. A battery of sixty-four cells was used to excite the engine. Some years later an electric engine was built by a Mr. Davidson, in Scotland, and tried on the Edinburgh and Glasgow Railway, but no great power was developed by it.

One reason why these engines developed so little power is the very limited sphere of magnetic attraction, and in order to overcome this disadvantage engines with axial magnets, or sucking-coils, were devised. In these a core of soft iron is drawn alternately into and out of a hollow coil as the circuit is made and broken, and the reciprocating rectilinear motion thus produced is transformed into a regular circular or rotary motion by a connecting-rod, a crank, and a fly-wheel. Our own countryman, Charles Grafton Page, contrived a great many such engines; and one of the simplest is shown in the engraving, Figure 145.

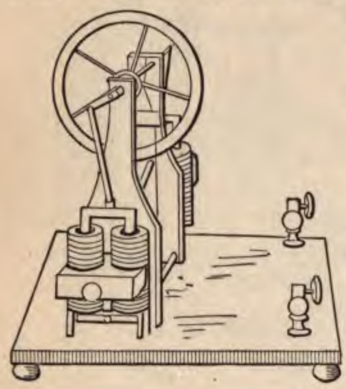

Fig. 145.

M. Froment, of France, has made one of the best of this class of motors. Figure 146 represents this machine. It is made on the same principle as those already described—that is, the successive break and make of the current through the several electro-magnets. These magnets, A, B, C, and D, are four in number, and are fastened on an iron frame, X. A drum carrying eight soft-iron armatures, M M, rotates between the electro-magnets. The battery current enters at the screw-post, K, passes through the machine, and leaves at the second terminal, H. The current is broken, and each magnet neutralized, just as the armature comes opposite to its poles; the magnetic power being restored at the moment when each armature has passed one-half the distance which separates each electro-magnet from the next. These changes are made by a suitable circuit-breaker arranged on the metal arc, O. In the figure this motor is represented as supplying power to turn a small mill.

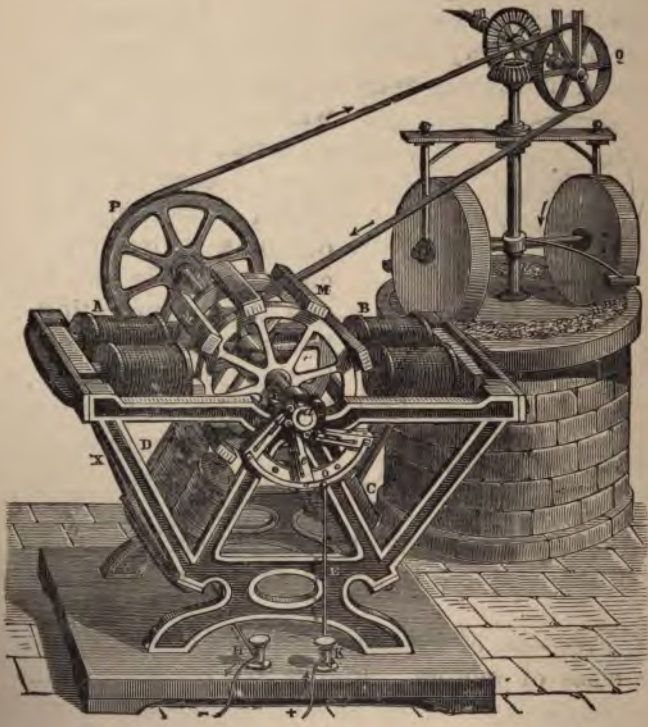

Fig. 146.

291. *Have such electro-magnetic motors been practically successful?*

No; several reasons have prevented this. In the first place, it is a physical impossibility for power derived from the consumption of zinc and acids in a voltaic battery to compete economically with power derived from the consumption of coal to produce steam. The consumption of the metal at the circuit-breaking points is also very rapid, necessitating close attention and militating against satisfactory work. Moreover, the power in such engines operates under great disadvantages, and the transformation of electro-magnetism into mechanical energy is attended with great loss, chiefly owing, as before indicated, to the fact of the rapid diminution of the attractive power of the magnet as the armature recedes from it, the said attraction varying inversely as the square of the distance.

Some years since the late Dr. Joule published his brilliant researches, in which he showed that the potential energy of zinc was so much lower than that of coal that it was impossible that a motor driven by the consumption of the former substance could ever successfully compete with steam, except in certain special cases where the power required is very light.

292. *On what principle may practical electro-motors be constructed?*

During the last ten years, electro-motors have not only become practical, but also numerous.

The principle upon which the modern electro-motor is constructed and practically operated is so well formulated by Franklin L. Pope, in a series of articles recently written for the "Electrical Engineer," and entitled "The Inventors of the Electric Motor," that we are willing to adopt the definition. It is stated by Mr. Pope to be "The method of producing mechanical power by the application of electro-magnetism, which consists in combining with a suitable source of electricity two systems of electro-magnets; one system mounted upon a shaft rotating continuously in one direction; the other fixed in relation thereto, and a commutator actuated by the rotation of said shaft, acting to instantly reverse the polarity of one of said systems, when by reason of their mutual attraction the revolution of the shaft has brought the poles of the moving magnetic system into coincidence with the poles of the fixed system."

It is now well known that this principle which underlies the modern electric motor was also embodied in a motor built as early as 1834 by Thomas Davenport, a blacksmith of Brandon, Vermont; a man far ahead of his time, who not only built electro-motors, but who used them for tractive purposes. Had the world been ready for the electro-motor, and had the source of supply also been ready, we should have had the motor fifty years ago.

The discovery and construction of the modern dynamo made possible the practical motor, which in its essentials is nothing but a dynamo made to act as a motor by passing a suitable current of electricity through it from some external source. In spite of Davenport's early work, it was not until about the year 1872 that electricians fully recognized the reversibility of the dynamo.

293. *How are dynamo-electric machines arranged to operate as motors, and how may power by their agency be transmitted?*

Power from any convenient source, such as a steam-engine or water-wheel, is caused to drive one dynamo-electric machine, a belt being carried from the motor to the armature-pulley of the machine, and the armature is thus rotated. The rotation of the armature between the magnet-poles develops electric currents in its coils, which, if led away by conducting wires connecting at their distant extremities with the terminals of a second dynamo-electric machine, cause the armature of the second machine to rotate rapidly in the opposite direction to that of the first; a pulley may be placed on the armature-shaft of the second machine, to which a belt is attached to convey the power thus reproduced wherever it is wanted.

The first machine thus generates the current, which is utilized in imparting motion to the second machine.

The work done by the original power is in the first machine transformed into electricity, and can then be conveyed or transferred by conducting wires to the different points where it is required; arriving at such points, it is passed through the armature and field-magnet coils of other machines, causing the armatures to rotate and to reconvert the electricity into motive power, which by any well-known means may then accomplish its work.

As much as sixty per cent. of the original power has in this manner been experimentally reclaimed under favorable circumstances; or, in other words, the pulley of the second machine has been known to exercise a power equal to sixty per cent. of the original power required to work the armature of the first or generating machine.

294. *Has electrical power so transmitted been utilized to any great extent? If so, where and how?*

The complete utilization of this important application of electricity is still in the future.

Already, however, it is employed to an enormous extent. Small motors whereby power can be distributed to any number of points and used only as required are much used throughout the civilized world. For this purpose the electrical transmission of power is very convenient. It requires no shafting. The supply wire can easily be led round corners; and power can more readily be economized.

The most interesting and important feature of the subject of electro-motion at present is the bearing which it has upon the railway problem.

Already it has been applied to the greater proportion of the American street-railways, and in other ways to locomotion in this and other countries. So far as the motor itself is concerned, the differences of the several styles employed are mainly structural.

But there are several different modes of enabling the electricity to reach the vehicle. The two broad methods are:

First. To provide a central station where dynamos are located and operated, and to connect the dynamos with conductors which are stretched along the side of the railway, continuing the circuit through the car motor by means of a traveling conductor, which forms one or both motor terminals, and which slides or rolls along the line-conductor, taking from it all the time electricity to work the car.

There may be two conductors stretched along the railway, in which case the circuit is metallic; or there may be but one, in which event the rails are employed as the return conductor. Furthermore, the line-conductor may be supported overhead in the form of a wire; it may be on the surface of the road in the form of an insulated rail; or it may be buried in an underground conduit from which it is insulated, and which is longitudinally slotted to receive the motor terminal.

Second. To provide a storage battery, and to carry it on the car, thus making each car not only a locomotive, but also a local motor.

295. *What are secondary batteries?*

Secondary batteries, frequently but erroneously called accumulators of electricity, are batteries which originally have no electro-motive force of their own, but are capable of being acted upon by an external source of electricity in such a manner that they acquire the power to give out an electric current opposite in direction to that of the external source by which they were treated. Secondary cells consist of two plates, of identical material or character, immersed in some suitable liquid, such as water. Normally such a cell can have no electro-motive force, because as the plates are alike and immersed in the same liquid there is no difference of potential between them, and consequently no E. M. F. and no tendency to set up a current of electricity. But if we connect such a cell in circuit with an active voltaic battery or a dynamo-electric machine, or, in fact, with any other generator of strong and constant direct currents, a result occurs which we may regard as the storage of electrical energy. It has been found that if the immersed plates are made of lead the secondary effects are more powerful and lasting than if other metals are used; therefore it has become customary to employ leaden plates in these batteries. Moreover, since it is well known that acidulated water has a much higher conductivity than pure water, and also aids the action of the charging current, it is usually employed as the liquid in which the plates are immersed. When the cell of leaden plates immersed in water acidulated with sulphuric acid is subjected to the action of the charging source, that plate which is connected with its positive pole, or, in other words, that plate of the secondary cell at which the current from the charging source enters, becomes covered with a spongy brown surface of peroxide of lead, while the other plate is deoxidized by the liberation of hydrogen from the dilute acid. When the leaden plates arrive at this condition the battery is said to be charged, and tends to furnish an electrical current, as already stated, in opposition to that of the charging current. If the original generator is now removed, and the wires leading from the two electrodes of the secondary cell are connected together by a conducting wire, so as to form a closed circuit, it will be found that a current of electricity will pass through it from the peroxidized plate to the other, the bright or deoxidized plate becoming gradually oxidized, and the oxidized surface of the other becoming gradually reduced to a less oxidized condition; and the current will continue to flow until the two leaden plates are again brought to a similar condition. This identical phenomenon operates in nearly all voltaic batteries to coat their own plates with the gases oxygen and hydrogen, and is called "polarization of plates."

296. *Give a short account of the history of the secondary cell.*

The history of the secondary cell dates from the year 1801. Gautherot, in that year, found that the wires of platinum or of silver, which had been employed as electrodes of a voltaic battery in the decomposition of salt water, acquired, and retained after they were disconnected from the battery, the power of yielding a transient current; this was, of course, due to polarization. In 1803 a philosopher of Jena, Ritter by name, observed the same phenomenon, using wires of gold; and, attaching some importance thereto, constructed the first secondary pile, which, like the pile of Volta, was an actual pile of discs, consisting of alternating discs of copper and moistened card, piled one upon another, and moistened with a solution of salt or sal-ammoniac.

It was found that this pile, after being connected for some time in the circuit of an ordinary voltaic battery, received a charge which was capable of giving a considerable shock. Ritter, however, did not succeed in discovering the underlying principle of this phenomenon, and the only result accruing from his experiments seems to have been that they attracted the attention of other experimenters. In 1842 Professor Grove constructed his gas-battery, which was a true secondary battery, in which the secondary currents were produced by the recombination of oxygen and hydrogen, previously separated, by electricity derived from an external source. M. Gaston Planté, as early as 1859, followed up these researches by vigorous and persevering experiments, and succeeded in producing a really valuable and practical secondary battery, which has been utilized for a variety of purposes: it has been made to produce light; it has been extensively employed in galvano-cautery and other surgical applications, in telegraphy, and even as a propelling power for velocipedes and pleasure-boats. Undoubtedly the present state of the electrical storage of energy, and our present knowledge of secondary cells, is due more to M. Planté than to any other person. No advance was made upon the battery of Planté until quite recently. In the spring of 1881 it was announced that "a box of electric energy equivalent to nearly a million foot-pounds" had been transported from Paris to Scotland in perfect safety. This statement was soon after confirmed by Sir William Thomson, to whom the box was consigned, and at the time attracted considerable attention. It was subsequently ascertained that this box was really an improved secondary battery, constructed upon the plan of M. Camille Faure, who in 1880 conceived the idea of giving to the two plates of the cell to be constructed a preliminary coating of red lead, which rendered them much easier of reduction to the necessary condition for speedy charging. By M. Faure's improvement the time spent in the formation of the cell was reduced from months to days. The ultimate result is the same as in the Planté cell—namely, the development, upon leaden plates immersed in acidulated water, of a coating of peroxide of lead, which may easily and quickly be reduced to the loosely crystalline metallic condition. By the process of "formation," in which the current from a dynamo-electric machine is sent through the secondary cells for several days without intermission, the coating of red lead is on one plate transformed gradually to a spongy metallic state, and on the other to a spongy surface of peroxide of lead.

Since the improvement of M. Faure was made public many modifications of his process, as also innumerable alternative methods of achieving the same result, have been introduced. It may be here stated that an important part of Faure's process was the protection of the red-lead coating of the plates by means of envelopes of flannel or felt; and that the great majority of his successors present no other novelty than to dispense with these envelopes, and to substitute perforations, channels, or grooves in the lead plates, by which the adhesion of the oxide is facilitated.

It was thought by many, upon the introduction of the Faure cell, that the difficulties attending the storage of electrical energy had all been overcome, and that results heretofore impossible were now to be gained; but it does not, after a lapse of two years, appear that these expectations have been realized, except to a very limited extent.

297. *Give a description of the Planté cell.*

A containing-vessel of any suitable material, such as glass or earthenware, is partly filled with a solution consisting of nine-tenths water and one-tenth sulphuric acid. In this liquid two sheets of lead rolled together, but kept from touching by strips of rubber rolled between them, are placed. Figure 147 represents the appearance of the sheets while being rolled, and also shows them after they are rolled into form.

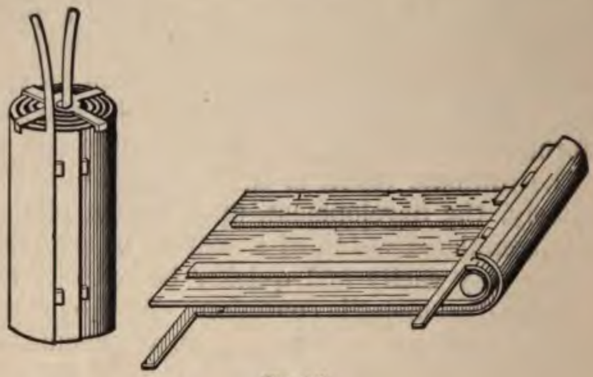

Fig. 147.

An air-tight stopper, in which is a hole for introducing or withdrawing the liquid and for the escape of gas, covers the vessel, which is very tall. The battery at this stage of its manufacture is represented by Figure 148. The whole is now surmounted by an ebonite cover, which is fitted with two binding-screws to attach to the wires of the charging battery, these terminals being permanently connected with the leaden plates. This cell, as already indicated, is inert until one of the electrodes becomes completely oxidized, which, when the cell is new, takes a very long time. When, however, the cell has once been brought to its proper condition it is recharged very quickly. The charging may be

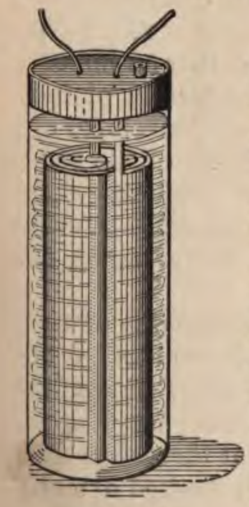

Fig. 148.

done by the use of two or three Grove or chromic-acid cells, as shown in the accompanying engraving, or by a dynamo-electric machine.

The "forming" of the cell, after it is once set up, simply consists in alternately passing the charging current through it and discharging it, each alternate charge being sent through the secondary cell in the opposite direction to the one immediately preceding. The time of each charge is gradually increased, and the work of formation thus goes on for several months, until a thoroughly formed cell is produced. The electro-motive force of this cell when fully charged may be as high as 2.38 volts; and as its internal resistance is not greater than 0.12 of an ohm, the current through a short wire of large size is of very considerable strength. As a method of

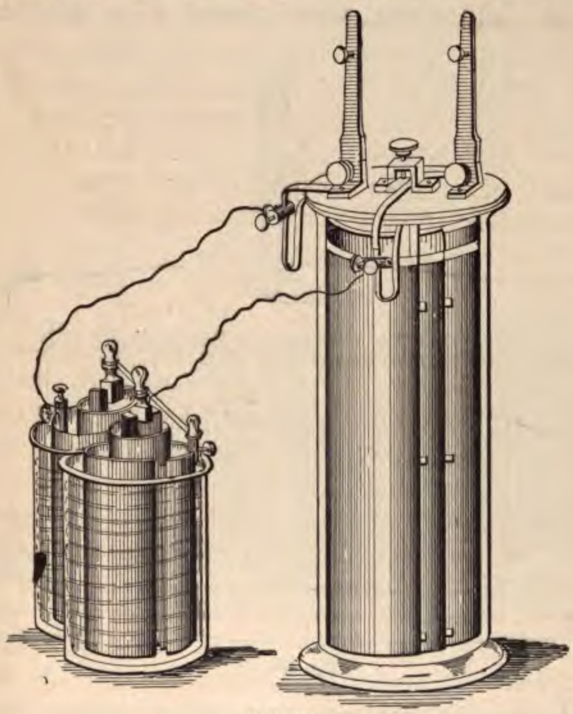

Fig. 149.

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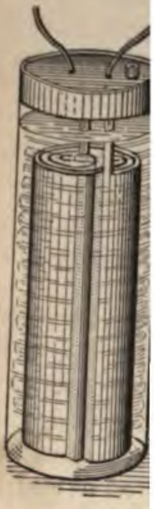

Fig. 148.

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tion it is rec

298. *How may a small secondary battery be easily constructed illustrating the foregoing principles?*

Take a glass of any convenient size and shape (a tumbler, for example), and nearly fill it with water acidulated with one-eighth of its bulk of sulphuric acid. Now cut two small strips of clean sheet-lead of a size to match the glass, perhaps three inches long, three-quarters of an inch wide, and one-sixteenth of an inch thick. A card-board cover may be made for the glass, with two slits cut in it so that the ends of the lead strips may be passed through and bent over; they are thus held in place, and the ends which pass through are fastened to wires. Couple up two or three cells of any battery (the gravity battery will do) in series, and one of the battery wires with one of the lead strips, and the other battery wire to the other strip. The lead strip attached to the wire leading from the positive pole of the battery will soon be seen to have a deposit of an oxide of lead formed on it. After the action has continued for a short time, if the battery wires are disconnected and the wires attached to the leaden plates are connected together with a galvanometer in circuit, a current may be observed passing in the opposite direction to the original current.

An ordinary gravity cell has an electro-motive force of about one volt. It takes about three volts to form a secondary cell; and when formed and completely charged it has an electro-motive force of about two volts.

299. *How is the secondary cell, as improved by Faure, constructed?*

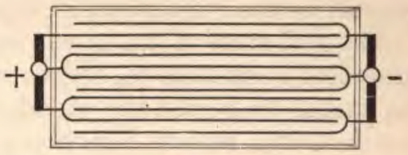

Fig. 151.

The improvement of M. Faure consists chiefly in the adaptation and adoption of devices which aid materially in shortening the tedious process of formation. This is accomplished by giving each of the leaden plates a thick coating of red lead prior to its immersion in the dilute acid. A box is provided with guides in the ends, and in these guides flat sheets of lead, heavily painted with a paste made of red lead and dilute acid, are placed; a piece of felt is pressed against each side, in order to retain the red lead in position. As indicated in the annexed diagram, the sheets of lead are arranged like the plates of a condenser; those attached to one end of the box being interleaved with those of the other end, but kept from touching them. All the sheets on one side are connected with a binding-screw, to which one of the leading-in wires is attached; and the sheets fixed to the other side are correspondingly connected together, and also with a second binding-screw for the other leading-in wire. The cell then presents the appearance shown in Figure 152. The box is filled up with dilute acid, and a charging current is sent through it for over a week, when the red lead is reduced gradually on one side to metallic lead, and on the other is developed into the peroxide of lead.

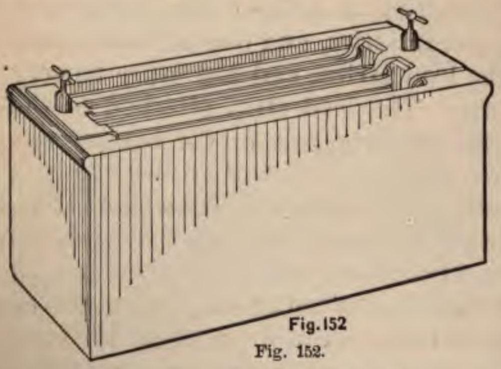

Fig. 152.

300. *What is meant by the popular expression, "storage of electricity"?*

The popular term is a misnomer, and rightly stated should be the "electrical storage of energy."

The real state of the case is that by means of electricity chemical work is done, and energy is thereby stored up; so that if we permit the chemical work to react electrical currents in a reverse direction are generated.

In other words, the phrase "storage or accumulation of electricity" means simply the combination, by means of electricity, of certain elements and compounds in a certain way, by which a tendency to react, and so produce electrical currents, is given to the said combination.

301. *Have secondary batteries become commercially successful?*

No; these batteries have, up to the present time, not been so successful or so useful as might have been expected from the statements made in regard to them when the Faure cell was first introduced; and it is very clear that a commercially successful and practical system of storage of electrical energy has yet to be developed. It is certain that a force which has once been evolved and utilized to do work must be more costly when reproduced than when first developed, by the cost of the work done; that is, even supposing there is no loss in the transformation, first, of electrical energy into chemical energy, and, secondly, of the chemical back again into electrical energy.

In point of fact, however, a considerable loss occurs in storage.

Several important considerations militate against the use of the secondary cell, made even in the best method now known.

These are as follows: The first cost, which is very great; the expense and time required in charging; their great weight and bulk—each cell weighing at least fifty pounds—and the necessity of a great number of cells to work even a single incandescent lamp. To these must be added the comparatively high internal resistance of the Faure cell, as generally constructed, some of them showing a resistance as high as half an ohm. It must be stated, however, that it has valuable qualities—namely, portability, lessened risk from high-tension currents, steadiness in production within certain limits, and also the fact that, although it takes a great number of cells to work one lamp, the same number can, properly arranged, operate several lamps.

There can be no doubt that if these batteries are eventually proved to be practical they will give a great impetus to electric lighting.

302. *Has electricity been applied to other purposes than those already described?*

Yes, the applications of electricity are too numerous to be mentioned here; many of the proposed applications of the force, however, are impractical and visionary.

It has been used as a means of measuring the velocity of rapidly moving bodies, such as cannon-balls, for performing upon musical instruments, for gas-lighting, and even for killing whales.

The only application which it is necessary to speak of here is that of gas-lighting. This has been done in several ways. By using a thermo-electric battery, and flashing a spark produced by the current between two platinum contact-points placed directly over the burner. In this case the current first attracts an armature and opens a conical gas-stopper; this plan is, therefore, well adapted for street-lighting. A second way is to arrange the secondary circuit of an induction-coil with points over each burner, making the circuit in a number of sections, so that one section can be lighted after another. This plan utilizes the secondary current. A third plan, much used in private houses and work-shops, is adapted for individual burners. Six or seven cells of a suitable battery are placed in circuit with a large, continuous coil of covered wire with a soft-iron core, and a circuit-closer also in the circuit is fixed upon each burner, so that the act of turning on the gas brings the two points of the circuit-closer into momentary contact with one another just over the escaping gas. The spark occurs at the moment when the points again separate, and is partly due to the extra current resulting from the self-induction of the convolutions of the coil, and partly to the magneto-currents generated by the demagnetization of the core.

CHAPTER XXIV.

ODDS AND ENDS.

THE tenacity of a copper wire is diminished after an electric current has for some time passed through it. In an iron wire the tenacity, in the same circumstances, increases.

A piece of wood cut from a tree is a good conductor; let it be heated and dried, it becomes an insulator; let it be baked to charcoal, it becomes a good conductor again; burn it to ashes, and it becomes once more an insulator.

Professor G. S. Ohm was born March 16, 1787; died July 7, 1854.

Wheatstone's bridge was devised by S. Hunter Christie in 1833, and is described in the "Philosophical Transactions," February 28, 1833.

According to Faraday, so small a quantity of electricity is stored in a Leyden jar that the decomposition of a single grain of water required 800,000 discharges of his large Leyden battery.

Sir Charles Wheatstone was born in 1802; died October 19, 1875, aged seventy-three.

The incandescent electric light was first patented in England by an American named Starr, in the name of Edward Augustin King. The number of the patent is 10,919, and the date November 4, 1845.

A. Graham Bell's first telephone patent was issued March 7, 1876, and is numbered 174,465.

The second patent for the Bell telephone bears date January 30, 1877, and number 186,787.

The resistance of the primary circuit of the induction-coil of a Blake transmitter is from two-tenths to three-tenths of an ohm.

The resistance of the secondary circuit averages about one hundred and fifty ohms.

The resistance of a Bell telephone-coil is about seventy-five ohms.

Speaking of duplex and other multiple telegraphs, Sabine's "History and Progress of the Electric Telegraph," republished in 1869, says: "Telegraphing in opposite directions, and telegraphing in the same direction, more than one message at a time, must be looked upon as little more than 'feats of intellectual gymnastics,' very beautiful in their way, but quite useless in a practical point of view."

The discovery of the Leyden jar was first announced in a letter addressed on the 4th of November, 1745, by Kleist, a Pomeranian ecclesiastic living in the town of Cammin, to Dr. Lieberkuhn, of Berlin.

It was rediscovered the following year by Cuneus, a pupil of Professor Muschenbroek.

Michael Faraday was born September 22, 1791, and died August 25, 1867.

The first practical electro-magnet was made in 1825 by William Sturgeon.

Du Verney, in 1700, was aware that the limbs of a frog were convulsed by the action of electricity.

Twenty-two years before that date "Swammerdam showed the Grand Duke of Tuscany that when a portion of muscle of a frog's leg, hanging by a thread of nerve, bound with silver wire, was held over a copper support so that both nerve and wire touched the copper, the muscle immediately contracted." Not until 1786 did Galvani make the same discovery, upon which was based the so-called science of galvanism, which was later ascertained to be one of the most useful developments of electricity.

It has been demonstrated by experiment in England that one mile of buried or submerged cable develops as much electro-static capacity as twenty-three miles of ordinary overhead wire.

Volta invented and described the electrophorus in 1776.

The first magneto-electric machine was constructed in 1833 by Pixii.

The Siemens armature was invented in 1857 by E. Werner Siemens, and is now universally employed in the well-known magneto-telephone bell.

Sulzer, of Berlin, in 1762, is believed to have been the first who noticed the peculiar taste occasioned by a piece of silver and a piece of lead when placed in contact with each other and with the tongue.

This is the earliest suggestion of the voltaic battery.

In 1800 Volta announced his invention of the battery.

It is stated in the 1852 edition of the "Encyclopædia Britannica" that in May, 1793, a voltaic pile was constructed and used by a Mr. John Robison, the publication of the account being made by Dr. Fowler, of Edinburgh.

The current generated in a magneto-telephone is estimated by De la Rue not to exceed that which would be produced by one Daniell cell in a circuit of copper wire four millimetres in diameter, and of a length sufficient to go two hundred and ninety times round the earth.

Oersted discovered in 1819 that a freely and horizontally suspended magnetic needle would deflect under the influence of an electric current.

The electric light was first produced by Sir Humphry Davy in 1802.

Faraday discovered that electricity could be produced from magnets in 1831.

The dynamo-electric machine is first described in a patent issued in England, October 14, 1854, to Soren Hjorth, and was reinvented in 1866 by four persons—Alfred Varley, who also patented his machine, Werner Siemens, Sir Charles Wheatstone, and Moses G. Farmer.

Galvanized iron wire, to have the same conductivity as the same length of copper wire, should weigh about six times as much per unit of length.

The resistance per mile of iron wire at sixty degrees Fahrenheit is ascertained in ohms by dividing 395,000 by the square of the diameter of the wire in mils.

A mil is one-thousandth of an inch.

The resistance of iron wire increases about thirty-five hundredths per cent. for each additional degree.

The resistance per mile of pure copper wire at sixty degrees Fahrenheit may be found by dividing 54,892 by the square of the diameter in mils.

The resistance of copper wire increases about twenty-one hundreths per cent. for each additional degree Fahrenheit.

Ampère, the founder of the science of electro-dynamics, was born in January, 1775; died in June, 1836.

The identity of lightning and electricity was discovered and demonstrated by Benjamin Franklin in 1747.

The first lightning-rod was erected by Franklin upon his own house in 1752.

Franklin, the father of American electricians, was born in Boston January 17, 1706, and died in Philadelphia April 17, 1790.

The first experimental gutta-percha insulated cable was made and submerged in September, 1847, at Bound Creek, between Newark and Elizabeth, New Jersey, by John J. Craven. A similar cable was laid by the Magnetic Telegraph Company across the Passaic River in February, 1848, and across the Hudson River June 15, 1848, the latter being one mile in length, all of which were successful.

The first long submarine telegraph-cable was laid across the English Channel in August, 1850.

When called upon to give his opinion concerning the nature of electricity, Faraday gave utterance to the following remarkable statement: "There was a time when I thought I knew something about the matter; but the longer I live, and the more carefully I study the subject, the more convinced I am of my total ignorance of the nature of electricity."

Philip Reis, the inventor of the now well-known Reis telephone, died January 14, 1874.

In Wheatstone's bridge systems, when the galvanometer resistance is greater than the battery resistance, the galvanometer should be made to connect the junction of the two greater resistances with that of the lesser.

The dip of the magnetic needle was discovered in 1576 by a compass-maker named Norman.

M. Steinheil, though not the first to use the earth as a portion of an electrical circuit, was the first to complete the circuit of a voltaic battery through the earth, and to use the earth circuit in telegraphy.

Steinheil died September 14, 1870

S. F. B. Morse, the inventor of the electro-magnetic telegraph, was born April 27, 1791; died April 2, 1872.

Professor Leonard D. Gale, in a deposition in connection with a telegraphic lawsuit in 1851, said: "I saw Mr. Morse translate a message, while in an adjoining room to the magnet, by the sound only. This was in the city of New York in 1837."

The first printing telegraph was invented by Alfred Vail in 1837.

The conducting power of carbon is much lower than that of the metals, and instead of decreasing, as in the metals, with a rise in temperature, it increases.

INTERNATIONAL MORSE CHARACTERS.

ALPHABET.

A - —
B — - - -
C — - — -
Ä - — - —
D — - -
E -
F - - — -
G — — -
É - - — - -
H - - - -
I - -
J - — — —
K — - —
L - — - -
M — —
N — -
O — — —
P - — — -
Ñ — — - — —
Ö — — — -
Q — — - —
R - — -
S - - -
T —
U - - —
V - - - —
W - — —
Ü - - — —
X — - - —
Y — - — —
Z — — - -

NUMERALS.

1 - — — — —
2 - - — — —
3 - - - — —
4 - - - - —
5 - - - - -
6 — - - - -
7 — — - - -
8 — — — - -
9 — — — — -
0 — — — — —

PUNCTUATION MARKS.

Period (.) - - - - - -
Comma (,) - — - — - —
Interrogation (?) - - — — - -
Exclamation (!) — — - - — —

TABLE I.—(*Continued*).

COPPER WIRE.

Birmingham Wire Gauge (Approximate).	Diameter.		Number of yards in 1 pound.	Weight in pounds of 1 mile (1760 yards).	Resistance of 1 mile of pure Copper at 32° Fahr.	Approximate weight of Silk required to cover a pound of Wire singly.
	Inches.	Millimetres.				Oz.
..	.028	.711	141.72	12.42	67.65	¾
23½	.026	.660	164.36	10.71	78.46	
24½	.024	.609	192.9	9.12	92.08	1
25	.022	.558	229.56	7.61	109.58	
26	.02	.508	277.78	6.33	132.59	
27	.018	.457	342.94	5.13	163.69	
28	.016	.406	434.03	4.05	207.17	
30	.014	.355	569.51	3.09	270.58	
31	.012	.305	771.60	2.28	368.30	1½
32	.01	.254	1111.11	1.58	530.35	
34	.0095	.241	1231.10	1.43	587.64	
..	.009	.228	1371.7	1.28	654.75	
35	.0085	.216	1537.8	1.14	734.05	
36	.008	.203	1736.1	1.01	828.67	2
..	.0075	.190	1975.3	0.8910	942.84	
..	.007	.177	2267.6	0.7761	1082.4	
37	.0065	.165	2629.9	0.6692	1225.3	2¾
38	.006	.152	3086.4	0.5702	1473.1	
..	.0055	.139	3673.1	0.4791	1753.2	
..	.005	.127	4444.4	0.3960	2121.4	
39	.0045	.114	5487.0	0.3207	2619.0	
40	.004	.106	6944.4	0.2534	3314.7	
..	.0035	.088	9070.3	0.1945	4329.4	
41	.003	.076	12346.0	0.1425	5892.7	
..	.0025	.063	17777.0	0.099	8485.6	

To find the percentage of conductivity in a sample of wire, pure copper being taken as = 100 :

Divide the resistance of 1 mile of pure copper wire of the same size (column 6) by the actual resistance of 1 mile of the wire tested (reduced to 32° Fahr), and multiply by 100.

TABLE II.

DIAMETER, WEIGHT, RESISTANCE, AND BREAKING STRAIN OF IRON WIRE—E. B. B.

(*Prescott.*)

B. W. Gauge No.	Diameter in thousandths of inch.	Resistance at 76° Fahrenheit.		Weight in pounds per mile.	Breaking strain in pounds.
		Feet per ohm.	Ohms per mile.		
1	300	1350	3.91	1249.7	4000
2	284	1211	4.36	1120.0	3400
3	259	1008	5.24	931.5	2900
4	238	958	5.51	886.6	2500
5	220	727	7.26	673.0	2200
6	203	618	8.54	572.0	1800
7	180	578	10.86	449.9	1520
8	165	409	12.92	378.1	1200
9	148	328	16.10	304.2	950
10	134	269	19.60	249.4	820
11	120	216	24.42	200.0	650
12	109	179	29.60	165.0	510
13	95	135	39.00	125.3	400
14	83	104	51.00	95.7	350
15	72	78	67.83	72.0	300
16	65	63	83.20	58.7	200
17	58	55	96.00	50.9	150
18	49	35.9	147.00	33.3	115
19	42	26.0	199.34	24.5	85
20	35	18.4	287.30	17.0	65

TABLE III.

SHOWING THE DIFFERENCE BETWEEN WIRE GAUGES.

No.	London.	Stubs.	Brown & Sharpe's.	No.	London.	Stubs.	Brown & Sharpe's.
0000	.454	.454	.460	19	.040	.042	.03589
000	.425	.425	.40964	20	.035	.035	.03196
00	.380	.380	.36480	21	.0315	.032	.02846
0	.340	.340	.32495	22	.0295	.028	.025347
1	.300	.300	.18930	23	.027	.025	.022571
2	.284	.284	.25763	24	.025	.022	.0201
3	259	.259	.22942	25	.023	.020	.0179
4	.238	.238	.20431	26	.0205	.018	.01594
5	.220	.220	.18194	27	.01875	.016	.014195
6	.203	.203	.16202	28	.0165	.014	.012641
7	.180	.180	.14428	29	.0155	.013	.011257
8	.165	.165	.12849	30	.01375	.012	.010025
9	.148	.148	.11443	31	.01225	.010	.008928
10	.134	.134	.10189	32	.01125	.009	00795
11	.120	.120	.09074	33	.01025	.008	.00708
12	.109	.109	.08081	34	.0095	.007	.0063
13	.095	.095	.07196	35	.009	.005	.00561
14	.083	.083	.06408	36	.0075	.004	.005
15	.072	.072	.05706	37	.0065	....	.00445
16	.065	.065	.05082	38	.00575	....	.003965
17	.058	.058	.04525	39	.005	....	.003531
18	.049	.049	.04030	40	.0045	....	.003144

TABLE IV.

APPROXIMATE WEIGHT OF INSULATED WIRES—AMERICAN GAUGE.

Braided Wire.

No. 4	8	ft.	to lb.
" 6	12	"	"
" 8	20	"	"
" 12	35	"	"
" 13	45	"	"
" 14	55	"	"
" 16	95	"	"
" 17	120	"	"
" 18	135	"	"
" 19	145	"	"
" 20	155	"	"

TABLE IV.—(*Continued*).

APPROXIMATE WEIGHT OF INSULATED WIRES—AMERICAN GAUGE.

Double-Wound Wire.

No.	4	8 ft. to lb.
"	6	12 " "
"	8	20 " "
"	18	160 " "
"	19	200 " "
"	20	225 " "

Owing to the difference in gauges, and to the fact that nearly every manufacturer has his own gauge, it is almost impossible to compile a standard table of the properties of iron wire with anything more than approximate exactness. Hence the figures in Table 2, which is taken from Mr. Prescott's book, is more a table of what the wire should be than what it is. The short table we give below will be found to be nearer the mark for the gauges to which it refers.

TABLE V.

STANDARD WEIGHT AND RESISTANCE OF GALVANIZED WIRE.

	No.	Resistance.	Weight.
Per mile.	6	10 ohms.	538 lbs.
"	7	12.1 "	461 "
"	8	14.1 "	389 "
"	9	16.4 "	323 "
"	10	20. "	264 "
"	11	25. "	211 "
"	12	32.7 "	163 "
"	14	52.8 "	97 "
"	16	91.6 "	57 "

TABLE VI.

RESISTANCE AND WEIGHT TABLE FOR COTTON AND SILK COVERED AND BARE COPPER WIRE—AMERICAN GAUGE.

The resistances are calculated for pure copper wire.

The number of feet to the pound is only approximate for insulated wire.

No.	Feet per pound.			Resistance, Naked Copper.			
	Cotton Covered.	Silk Covered.	Naked.	Ohms per 1000 feet.	Ohms per mile.	Feet per ohm.	Ohms per pound.
8	....	....	20	.6259	3.3	1600.	.0125
9	....	....	25	.7892	4.1	1272.	.0197
10	....	....	32	.8441	4.4	1185.	.0270
11	....	....	40	1.254	6.4	798.	.0501
12	42	46	50	1.580	8.3	633.	.079
13	55	60	64	1.995	10.4	504.	.127
14	68	75	80	2.504	13.2	400.	.200
15	87	95	101	3.172	16.7	316.	.320
16	110	120	128	4.001	23.	230.	.512
17	140	150	161	5.04	26.	198.	.811
18	175	190	203	6.36	33.	157.	1.29
19	220	240	256	8.25	43.	121.	2.11
20	280	305	324	10.12	53.	99.	3.27
21	360	390	408	12.76	68.	76.5	5.20
22	450	490	514	16.25	85.	61.8	8.35
23	560	615	649	20.30	108.	48.9	13.3
24	715	775	818	25.60	135.	39.0	20.9
25	910	990	1030	32.2	170.	31.0	33.2
26	1165	1265	1300	40.7	214.	24.6	52.9
27	1445	1570	1640	51.3	270.	19.5	84.2
28	1810	1970	2070	64.8	343.	15.4	134.
29	2280	2480	2617	81.6	432.	12.2	213.
30	2805	3050	3287	103.	538.	9.8	338.
31	3605	3920	4144	130.	685.	7.7	539.
32	4535	4930	5227	164.	865.	6.1	856.
33	....	6200	6590	206.	1033.	4.9	1357.
34	....	7830	8330	260.	1389.	3.8	2166.
35	....	9830	10460	328.	1820.	2.9	3521.
36	....	12420	13210	414.	2200.	2.4	5469.

TABLE VII.

SHOWING THE RELATIVE CONDUCTIVITY AND RESISTANCE OF METALS.

Pure Metals.	Conductivity—Silver at 32° being 100.	Resistance—Silver at 32° taken as 1.
Aluminum	33.76	2.96
Antimony	4.62	21.65
Arsenic	4.76	21.01
Bismuth	1.25	80.00
Cadmium	23.72	4.21
Cobalt	17.22	58.07
Copper (hard)	99.95	1.00
" (soft)	97.95	....
Gold	77.96	1.28
Iron	16.81	5.95
Lead	8.32	12.02
Mercury	1.63	61.35
Nickel	13.11	7.63
Platinum	18.03	5.55
Silver (hard)	100.	1.
" (soft)	108.57	0.92
Thallium	9.16	10.92
Tin	12.36	8.09
Zinc (pressed)	29.02	3.44
Graphite	0.69	145.00

TABLE VIII.

SHOWING THE RELATIVE RESISTANCES OF LIQUIDS.

(*Becquerel.*)

Copper taken as standard	1
Solution sulphate of copper, saturated	16,855,520
" " " diluted to half	26,327,637
" " of zinc, saturated	15,861,267
" " " diluted to half	12,835,836
Chloride of sodium (common salt) saturated	2,903.538
Chloride of sodium, diluted to half	3,965,421
Sulphuric acid, diluted 1 to 11	1,032,020
Nitric acid	976,000
Distilled water	6,754,208,000

TABLE IX.

THE STANDARD WIRE GAUGE.

Adopted by the National Telephone Exchange Association, September 8, 1885. (New English Board of Trade, Standard Wire Gauge, Legalized March 1, 1884.)

TABLE OF DIMENSIONS, WEIGHTS AND RESISTANCES OF COPPER AND IRON WIRE.

Compiled by C. H. Barney, Secretary of the National Telephone Exchange Association.

Number of Standard Gauge.	Diameter.		Pure Copper Wire.				Galvanized Iron Wire.		Number of Standard Gauge.
			Weight, Sp. Gr., 8.90.		Resistance at 59.9° Fahr.				
	In Mils. (.001 in.)	In Millimetres.	Lbs. per 1,000 feet.	Lbs. per Mile.	Ohms per 1,000 feet.	Ohms per Mile.	Weight, Sp. Gr., 7.74. — Lbs. per Mile.	Resistance at 59.9° Fahr. — Ohms per Mile.	
7-0	500	12.700	756.28	....	....	....	....	....	7-0
6-0	464	11.785	651.31	....	....	....	....	....	6-0
5-0	432	10.973	564.44	....	....	....	....	....	5-0
4-0	400	10.160	484.03	....	....	....	....	....	4-0
3-0	372	9.449	418.63	....	....	....	....	....	3-0
2-0	348	8.839	366.36	....	....	....	....	....	2-0
0	324	8.229	317.54	1676.61	.095774	.50558	....	....	0
1	300	7.620	272.27	1437.58	.11171	.58982	....	....	1
2	276	7.010	230.44	1216.72	.13199	.69690	....	....	2
3	252	6.401	192.11	1014.34	.15832	.83592	....	....	3
4	232	5.893	162.83	859.74	.18680	.98630	747.68	6.6884	4
5	212	5.385	135.96	717.87	.22370	1.18113	624.30	8.0100	5
6	192	4.877	111.52	588.82	.27273	1.4400	572.07	9.7656	6
7	176	4.470	93.71	494.78	.32458	1.7137	430.29	11.6222	7
8	160	4.064	77.445	408.89	.39273	2.0736	355.60	14.0625	8
9	144	3.658	62.730	331.21	.48486	2.5600	288.04	17.3611	9
10	128	3.251	49.565	261.70	.61365	3.2400	227.59	21.9726	10
11	116	2.946	40.707	214.93	.74718	3.9451	186.92	26.7539	11
12	104	2.642	32.720	172.76	.92955	4.9080	150.24	33.2840	12
13	92	2.337	25.605	135.19	1.1878	6.2715	117.57	42.5331	13
14	80	2.032	19.361	102.22	1.5709	8.2943	88.90	56.2500	14
15	72	1.829	15.683	82.80	1.9394	10.2400	72.01	69.4444	15
16	64	1.626	12.391	65.42	2.4546	12.9602	56.89	87.8906	16
17	56	1.422	9.4869	....	3.2060	....	....	....	17
18	48	1.219	6.9700	....	4.3637	....	....	....	18
19	40	1.016	4.8403	....	6.2837	....	....	....	19
20	36	0.914	3.9206	....	7.7577	....	....	....	20
21	32	.813	3.0978	....	9.8184	....	....	....	21
22	28	.711	2.3708	....	12.824	....	....	....	22
23	24	.610	1.7425	....	17.455	....	....	....	23
24	22	.559	1.4642	....	20.773	....	....	....	24
25	20	.508	1.2100	....	25.135	....	....	....	25
26	18	.457	0.98015	....	31.031	....	....	....	26
27	16.4	.4166	.81365	....	37.381	....	....	....	27
28	14.8	.3759	.66263	....	45.90	....	....	....	28
29	13.6	.3454	.55953	....	54.358	....	....	....	29
30	12.4	.3150	.46515	....	65.388	....	....	....	30
31	11.6	.2946	.40707	....	74.718	....	....	....	31
32	10.8	.2743	.35286	....	86.197	....	....	....	32
33	10.0	.2540	.30252	....	100.541	....	....	....	33
34	9.2	.2337	.25605	....	118.79	....	....	....	34
35	8.4	.2134	.21346	....	142.49	....	....	....	35
36	7.6	.1930	.17473	....	174.07	....	....	....	36
37	6.8	.1727	.13988	....	216.94	....	....	....	37
38	6.0	.1524	.10891	....	279.28	....	....	....	38
39	5.2	.1321	.08180	....	371.82	....	....	....	39
40	4.8	.1220	.06970	....	436.37	....	....	....	40

The resistances in the above table are calculated from Dr. Matthiessen's standard (1 mile of pure copper wire of 1-16th inch diameter equals 13.59 ohms at 59.9° Fahr.).

The resistance of pure copper wire increases as the temperature rises, about 0.21 per cent. for each additional degree F.

The resistance of iron wire increases as the temperature rises, about 0.35 per cent. for each additional degree F.

TABLE OF RELATIVE CONDUCTIVITIES.

Silver,
Copper,
Gold,
Zinc,
Platinum,
Iron,
Tin,
Lead,
Mercury,
Carbon,
Acids,
Saline Solutions,
Rarefied Air,
Melting Ice,
Distilled Water,
Stone,
Dry Ice,
Dry Wood,
Porcelain,
Dry Paper,
Wool,
Silk,
Glass,
Sealing Wax,
Sulphur,
Resin,
Gutta-Percha,
India-Rubber,
Shellac,
Paraffine,
Ebonite,
Dry Air.

There is no known absolute conductor. In the foregoing table each substance conducts better than the one which follows it.

ELECTRO-MOTIVE FORCE OF BATTERIES IN VOLTS.

	Volts.
Daniell	1.079
Grove	1.956
Smee, when not in action	1.102
“ when in action	.510
Bunsen	1.926
Bichromate or Chromic Acid	1.967
Marie Davy	1.533
Leclanché	1.662
Planté secondary	2.100
Faure “	2.100

RELATIVE INDUCTIVE CAPACITIES OF THE PRINCIPAL INSULATING SUBSTANCES.

Standard being air, taken as		100
Resin	is	177
Pitch	“	180
Beeswax	“	186
Grass	“	190
Sulphur	“	193
Shellac	“	195
Paraffine	“	198
India-rubber	“	280
Gutta-percha	“	420
Mica	“	500

The above are from Jenkin's “Electricity and Magnetism.”

(*From Culley's Hand-book.*)

METRIC WEIGHTS AND MEASURES.

Millimetres.	Inches.	Millimetres.	Inches.	Millimetres.	Inches.
1	0.039	45	1.771	125	4.941
2	0.078	50	1.968	130	5.118
3	0.118	55	2.165	135	5.315
4	0.157	60	2.362	140	5.512
5	0.197	65	2.559	145	5.708
6	0.236	70	2.756	150	5.906
7	0.275	75	2.953	155	6.103
8	0.315	80	3.149	160	6.299
9	0.354	85	3.346	165	6.496
10	0.394	90	3.543	170	6.693
15	0.590	95	3.740	175	6.890
20	0.787	100	3.937	180	7.087
25	0.984	105	4.134	185	7.284
30	1.181	110	4.331	190	7.480
35	1.378	115	4.528	195	7.677
40	1.575	120	4.744	200	7.874

1 inch = 25.4 millimetres.

	Inches.	Feet.	Yards.
1 Millimetre	0.039	....	....
1 Centimetre....	0.393	....	....
1 Decimetre	3.937	....	....
1 Metre........	39.370	3.280	1.093
1 Kilometre.....	39,370.790	3,280.899	1,093.633

Miles.....	1	2	3	4	5	6	7	8	9
Kilometres	1 609	3 219	4 828	6 437	8 047	9 656	11.265	12.874	14.484

	Grains Troy.	Pounds Avoirdupois.
1 Milligramme.......	0.015	....
1 Centigramme.......	0.154	....
1 Decigramme.......	1.543	....
1 Gramme...........	15.432	....
1 Kilogramme.......	15,432.348	2.2046
2 Kilogrammes......	....	4.4092
3 "	....	6.6138
4 "	....	8.8184
5 "	....	11.0230
6 "	....	13.2276
7 "	....	15.4322
8 "	....	17.6368
9 "	....	19.8414

7,000 grains Troy = 1 pound Avoirdupois.

1 Litre = 35.275 fluid ounces = 1.764 pints = 61.024 cubic inches.

1 cubic centimetre = .0610 cubic inches.

INDEX.

Aerial cables, 181 ; description of, 182.
Alarms, electric, operated by clock-work, 328.
Alphabet, Morse telegraphic, 354, 355.
Amalgamation of zincs, 25.
Amber, 9.
Ampère, 95.
Applications (miscellaneous) of—
  Blasting, 329, 332.
  Clock-alarms, 328.
  Electric bells, 286, 298.
  Electric clocks, 323, 327.
  Electricity, 266.
  Electric lighting, 266, 280.
  Electric-metallurgy, 281, 285.
  Electro-motion and transmission of power, 332, 340.
  Electro-therapeutics, 318, 322.
  Gas-lighting, 348.
  Storage of electric energy, 340, 349.
  Telephony, 299, 317.
  Time-balls and guns, 328.
Armature, 48.
  Siemens, 67, 353.
Arrangement of batteries for maximum effect with given number, 148, 150.
Artificial magnet, 44.
Astatic galvanometer, 100.
Attraction of magnets, 44.
Automatic circuit-breaker, 83.

Bar magnet, 48.
Batteries, electric, 18.
  Best arrangement for given number of cells, 148, 150.
  Bunsen, 26.
Batteries—
  Callaud, 26.
  Care of batteries, 32, 34.
  Chromic acid, 26.
  Daniell, 26.
  Depolarizing mixture batteries, 26.
  Earth, 42.
  Gravity, 26.
  Grove, 26, 28.
  Internal resistance of, 118, 121
  Invention of, 353.
  Leclanché, 26, 30.
  Local action in, 25.
  Other methods of arranging, 145.
  Poles of, 31.
  Proportionment to short lines, 148.
  Rule for obtaining greatest magnetic effect from, 146.
  Secondary, 338.
  Single-fluid, 26.
  Smee, 26.
  Thermo-electric, 37.
  Two-fluid, 26.
  Usual arrangement of, for telegraph lines, 136, 144.
  Voltaic, 24.
  Watson, 26.
Bells, electric (see *electric bells*, 286).
Blasting by electricity, 329.
  Frictional, 330.
  Relative advantages, 332.
  Voltaic, 331.
Brush dynamo, 74, 76.

Cables, aerial, 181.
  Description of principal forms, 181, 182.
  Submarine, 189, 191, 353.
Candle, electric, 277, 279.

Carbon battery, 29.
Circuits, voltaic, 142, 152.
  Arrangement of, to connect register or sounder, 217.
  Conditions of current strength in, 144.
  Constitution of, 142.
  Earth as part of, 142, 144.
  Faults, 231, 233.
  Testing, 233, 241.
Circuit-breaker, 83.
  Automatic, 83.
Circuit-changers, 200.
Circuit-closers, press-button, 291.
  Pull, 292.
Clocks, electric, 323.
  Bain's clocks, 323, 326.
  Description of, 324.
  Governed clocks, Jones system, 326.
  Shepherd system, 327.
Closed-circuit system of telegraphy, 133, 135.
Coercive force of magnets, 48.
Compound magnets, 48.
Condensers, 85, 86.
Coulomb, 95.
Cross-arms, 155.
Crosses, in telegraph or telephone lines, 232.
  Swinging, 233.
  To test for, 239.
  Weather, 233, 240.
Current strength, 92, 93.
  Conditions of, in a circuit, 144.
  How varied, 93.
Cut-outs, 203.

[illegible] 6, 28.

[illegible] ensate shunted,

[illegible] ier, 105.
[illegible] c, 46.
[illegible] ak, in electric

Disconnection in district systems, 235.
  Intermittent, 235.
  Partial, 236.
  To test for, 233.
District telegraphs, 137.
Duplex telegraphy, 242.
  Bridge, 247.
  Differential, 245.
  Gintl's, 243.
  Historical sketch of, 243.
  Sabine's opinion of, 350.
  Stearns's, 244, 249.
Duplicate transmission in same direction, 249.
Du Vernay's anticipation of Galvani's discovery, 350.
Dynamic induction, 19.
Dynamo-electric machines, 70, 79.
  Arrangement to act as motors, 336.
  Brush, 74, 76.
  Gramme, 72, 74.
  Invention of, 353.
  Reversibility of, 335.
  Ring-armature machines, 72, 76.
  Term defined, 76.
  Uses of, 79.

Earth battery, 42.
Earth circuit, 142, 144.
  Early examples of, 143.
  First utilization in telegraphy, 142.
Earth currents, 41.
  Method of obviating effects of, 41.
Earth faults, 231.
  Intermittent, to test for, 239.
  Swinging, 232.
  To test for, 237.
Earth wires, in offices, 193, 228.
  Defective, 233, 240.
  For lightning-arresters, 195.
  For testing purposes, 195.
  Proper construction of, 194.
  Uses of, 193.
Electrical machines, 12.
  Cylinder machine, 14.

Electrical Machines—
  Holtz machine, 16.
  Plate machine, 13.
Electrical measurement, 98, 129.
Electrical resistance, 91.
  Of wires, 91, 92.
Electrical units, 93, 97.
Electric battery, 18.
Electric bells, 286.
  Arrangements for various bell circuits, 292, 296.
  Construction of simple bell circuit, 290.
  For telephone lines, 297.
  Individual, 297.
  Magneto, 297.
  Polarized, 288.
  Press-buttons for, 291.
  Pull circuit-closer, 292.
  Single-stroke, 287.
  Vibrating, 287.
Electric clocks (see *clocks, electric*, 323).
Electric gas-lighting, 350.
Electricity a form of energy, 9.
  Atmospheric, 20.
  Battery, 18.
  Conductors of, 11.
  Distribution of, 18.
  Dynamical, 17.
  Electrical machines, 12, 16.
  Electrics and non-electrics, 12.
  Electrometer, 12.
  Electrophorus, 14.
  Electroscope, 12.
  Frictional, 10, 20.
  Magneto, 20, 59.
  Methods of developing, 20.
  Miscellaneous applications of, 236.
  Non-conductors of, 11.
  Oersted's discovery, 353.
  Plus and minus, 11.
  Positive and negative, 10.
  Relationship to magnetism, 50, 51.
  Statical, 17.
  Thermo, 20.
Electricity—
  Vitreous and resinous, 10.
  Voltaic or galvanic, 22.
Electric lighting, 266.
  Arc, 266.
  Arc lamps, 268.
  Brush lamp, 269.
  Divisions of, 266.
  Edison's lamp, 275.
  Electric candle, 277.
  First produced, 353.
  Illuminating power of, 277.
  Incandescent, 273.
  Jablochkoff candle, 277.
  Lane-Fox lamp, 276.
  Maxim, Bernstein, and Weston lamps, 277.
  Semi-incandescent lamps, 279.
  Starr's lamp, 274.
  Sun lamp, 280.
  Swan's lamp, 276.
  Wilde's candle, 278.
Electric potential, 89, 90.
Electric quantity, 92.
  Term applied to current electricity, 92.
  Applied to static electricity, 92
Electrics and non-electrics, 12.
Electrodes, 32.
Electro-dynamic induction, 19.
Electrolysis, 32.
Electrolytes, 32.
Electro-magnet, 19, 52.
  Construction of, 52.
  For long circuits, 56.
  For short circuits, 56.
  Length of core, 54.
  Resistance of, 54.
  When devised, 53, 352.
Electro-magnetic induction, 19.
Electro-magnetism, 52.
  Laws of, 54, 55.
Electro-metallurgy, 281.
  Electro-plating, 281, 283.
  Electro-typing, 283.
  General explanation of, 281.
  Outline of art, 283.

Electrometer, the, 12.
Electro-motion, and transmission of power, 332.
  Dynamo-machine as a motor, 336.
  Froment's motor, 333.
  Jacobi's motor, 332.
  Page's motor, 333.
  Power electrically transmitted, 337, 340.
  Railways, 337, 338.
  Reversibility of dynamo-machine, 335.
Electro-motive force, 90.
  Comparison of, 124.
  Measurement of, 125, 126.
  Of batteries, 90, 91.
Electrophorus, 14, 358.
Electroscope, 12.
Electro-static induction, 18.
Electro-therapeutics, 318.
  Definitions of, 319.
  Electrical probe, 321.
  Electro-physiology, definition of, 318.
  Electro-surgery, 320.
Energy, definition of, 9.
Escape in telegraph or telephone lines, 232.
  To test for, 238.
Extra current, 84, 85.

Farad, 95.
Fire-alarm telegraphs, 136.
Frictional electricity, 10.
  Applications of, 20.

Galvanometer, the, 98.
  Astatic, 100.
  Constant of, 113.
  Definition of, 98.
  Differential, 105, 107.
  Invented by Schweigger, 99.
  Resistance, measurement of, 121, 123.
  Sine, 104.
  Tangent, 101, 104.
Galvanometer—
  Thomson's reflecting, 107, 110.
  To reduce deflection of, 123.
  Uses of, 100.
  Wheatstone's bridge, 110, 113.
Gas-lighting, electric, 348.
Gauge, wire, 167, 363.
Gramme machine, 72, 74.
Gravity batteries, 26.
  Care of, 33.
  Reactions of, 28.
Ground wires, 193, 196, 228.
  For lightning-arresters, 195.
  For testing purposes, 195.
  Should be soldered, 195.
  To construct, 194.
  Uses of, 193.
  When to be used, 228.
Grounds in telegraph or telephone lines, 231.
  Intermittent, 239.
  Swinging, 232.
  To test for, 237.
Grove battery, 26, 28.
  Care of, 33.

Harmonic telegraph, 254.
  Gray's, 255.
Holtz's electrical machine, 16.
  Reversibility of, 16.
Horseshoe magnets, 48.

Illuminating power of the electric light, 277.
Individual signals, 297.
Induction, 18.
  Dynamic, or voltaic, 19.
  Electro-magnetic, 19.
  Electro-static, 18
  Magnetic, 20, 45, 46.
  Magneto-electric, 19, 59.
Induction-coil, 80.
  Circuit-breaker, 83.
  Condenser, use of, 85.
  Description of large coils, 87.
  Primary circuit of, 82.
  Secondary coil of, 82.

Induction-coil—
  Soft-iron core, 86.
  Use of in telephone transmitters, 309.
  Uses of, 88.
  What it is, 80.
  Why so called, 80.
Insulators for land lines, 159.
  Brooks's, 164.
  Earthenware, 163.
  Glass, 163.
  Requisite qualifications of, 162.
  Rubber hook, 165.

Joint resistance, 150.
  Calculation of, 151.
Joints or splices in line-wire, 177.
  Bell-hanger's joint, 178.
  Britannia joint, 178.
  Soldering, 178.
  Twist joint, 178.

Kerite, what it is, 184.
Keys, telegraph, 211.
  Care of, 226.
  Defects in operation, 225.
  Morse, 211.
  Open-circuit, 213.
  Reversing, 213.

Ladd's dynamo-electric machine, 70, 72.
Lamps, arc, 268, 273.
  Incandescent, 273, 277.
  Semi-incandescent, 279.
  Sun, 280.
Leakage-conductors for land lines, 160.
Leclanché battery, 26, 30.
  Care of, 34.
Leyden jar, 17.
  When discovered, 17, 350.
Light, electric, 266, 280.
Lightning-arrester, 201, 203.
Lightning-rod, 20.
Line construction, 153.
  Conductors, material of, 165.
Line—
  Cross-arms for, 155.
  Dip of, 175.
  Insulators, 159, 162, 165.
  Joints or splices, 177, 179.
  Poles for use in, 153, 155.
  Sizes of, 166, 169.
  To ascertain proper dip, 175.
Lines, house-top, 155.
  Supports for, 156, 159.
Lines, supplying a number from one battery, 146.
Line-wire, 165, 175.
  Aerial cables, 181.
  For telephone lines, 168, 170.
  Galvanized, 170.
  Humming in, 179.
  Iron, 165.
  Method of leading into terminal station, 180.
  Method of leading into way-station, 179.
  Sizes chiefly used, 152, 165.
  Steel, 169.
Liquids, resistances of, 118.

Magnet, 43.
  Artificial, 44.
  Natural, 43.
Magnet, properties of, 44, 46.
  Bar, 48.
  Compound, 48.
  Dip, 46.
  Horseshoe, 48.
  Permanent, 47.
  Polarity, 46.
Magnetic field, 49.
Magnetic induction, 20, 45, 46.
Magnetism, 43.
  Relationship to electricity, 50.
  Residual, 53.
  Rule for obtaining maximum effect from given battery, 146.
Magnetization, process of, 49.
Magneto-bells, 297.
Magneto-electric induction, 19, 59.
  Discovery of, 353.

Magneto electricity, 20, 59.
  Advantages of, 62.
  Applications of, 61, 63.
Magneto-electric machines, 60, 65.
  Definitions of, 60, 65.
  First invented, 60.
  Mutual accumulation machines, 69, 70.
  Wilde's, 68, 69.
Measurement of resistance, 115, 123.
  By differential galvanometer, 116.
  By substitution, 116.
  Internal resistance of batteries, 119, 121.
  Land lines, dispensing with earth-wires, 117.
  Resistance of galvanometer, 121, 123.
  Using Wheatstone bridge, 116, 117.
Miscellaneous applications of electricity, 266.
  Electric bells, 286.
  Electric lighting, 266.
  Electro-metallurgy, 281.
Morse's telegraph, 133, 136.
  Alphabet, 354, 355.
  Instruments, 196.
  Key, 211.
  Register, 215.
  Relay, 206, 209.
  Repeaters, 218, 221.
  Sounder, 214.
Multiple telegraphy, 242.
  Duplex, 242, 250.
  Electro-harmonic, 254, 265.
  Quadruplex, 250, 254.
Multiplying power of shunts, 128.

Odds and ends, 349, 353.
Office-wire, 192.
  Practical arrangement of, 192.
Ohm, 94.
Ohm's law, 96.
  Application of, 97.

Partial disconnection, 231.
Partial disconnection, to test for, 236.
Permanent magnet, 47.
Plates of battery, 31.
Polarity of magnets, 46, 47.
Polarization, voltaic, 23.
  Explanation of, 23.
  Injurious effects of, 24.
  Methods of obviating, 24.
Polarized bells, 288.
Polarized relay, 209, 211.
Poles of battery, 31.
Poles, for telegraph lines, 153.
  Setting up of, 154.
Police telegraph, 139.
Potential, definition of, 89.
  A relative term, 89, 90.
  Difference of, 90.
Properties of magnets, 44, 46.
Proportionment of battery power for short lines, 148.

Quadruplex telegraphy, 250, 254.
  Changes and improvements in, 253.
  Edison's, 251.
  Historical sketch of, 250.
Quantity, 92.
  Definition of, 92.

Railways, electric, 337.
Register, telegraphic, 215.
  Adjustments, and management of, 226.
Relay, telegraphic, 206.
  Adjustments, 208, 222, 225.
  Construction, 206.
  Polarized, 209, 211.
  Use of, 206.
Repeaters, telegraphic, 218, 221.
  Bulkley's, 218.
  Button, 218.
  Edison's, 221.
  Uses of, 218.
Repulsion of magnets, 45.
Residual magnetism, 45.
Resistance, 91.

Resistance—
  Internal of battery, 118.
  Measurement of, 119, 121.
  Of any given wire, 91, 92.
  Of a telegraph line, 91.
  Of battery in reference to entire circuit, 53.
  Of cells in common use, 119.
  Of electro-magnets, 54.
  Of human body, 321.
  Of liquids, 118.
Resistance-coils, 114.
Resistance, joint, 150.
  Calculation of, 151.
Resistances, measurement of, 115, 123.
  By differential galvanometer, 116.
  By substitution, 116.
  By tangent galvanometer, 120.
  By Wheatstone's bridge, 116, 117.
Retardation, 188.
Rheostat, and resistance-coils, 113, 115.
  Present arrangement, 114
  Wheatstone's, 113.
Robison's anticipation of Volta's invention of the "voltaic pile," 351.
Ronald's underground line, 184.

Secondary batteries, 338, 347.
  Faure cell, 340, 345.
  Historical sketch of, 339.
  Planté cell, 341.
  Small size Planté, 345.
Shunts, 126, 129.
  Compensation of shunted deflections, 128.
  Definition of term, 126.
  Their use, 126.
  To ascertain multiplying power of, 128.
  Value of shunts, 127.
Siemens armature, 67.
Signals for telephone lines, 297.
Sine galvanometer, 104.
Single-fluid battery, 26.
Single-stroke electric bells, 287.
Soldering joints in line-wire, 178.
Sounder, 214.
  Adjustments of, 226.
Spring-jacks, 205.
Static, and dynamic, definition of, 16.
Static induction, 18.
Storage of electric energy, 340, 346, 347.
Submarine cables, 189.
  Adaptation for telephony, 190.
  Insulating material employed in, 189.
Subterranean lines, 184.
  Adaptation for telephonic circuits, 185.
  Conductor usually employed, 184.
  First laid, 184.
  Static induction in, 185.
  Where now used, 185.
Sulzer's experiment in voltaic electricity, 351.
Swammerdam's anticipation of Galvani's discovery, 350.
Switchboard, 197.
  Universal, 197.
  Uses of, 197.
  Western Union pin, 198.
Switches, and circuit-changers, 200.
  Automatic telephone, 200, 315, 317.
  Button, 200.
  Cut-out, 203.
  For changing circuit between sounder and register, 217.
  Plug, 200.
  Secrecy, 200.

Tables, of copper wire, 356, 357, 359.
  Diff. between wire-gauges, 359.
  Electro-motive force of batteries, 364.
  Iron wire, 358.
  Metric weights and measures, 365, 366.
  Relative conductivities, 364.
  Relative conductivity and resistance of metals, 362.
  Wire-gauge standard, 363.

Tables—
  Relative inductive capacity of insulators, 364.
  Relative resistance of liquids, 362.
  Weight and resistance of covered and bare copper wire, 361.
  Weight and resistance of galvanized iron wire, 358.
  Weights of insulated wire, 360.
Tangent galvanometer, 101, 104.
Tangents, 101.
Telegraph, Morse American, 133, 136.
  Alphabet, 356, 357.
  Arrangement of batteries, 136, 144.
  Circuit arrangement of, 133.
  Key, 211, 213.
  Local circuit, 135.
  Proportionment of batteries, 145.
  Register, 215.
  Relay, 206, 209.
  Repeaters, 218, 221.
  Setting up instruments, 196.
  Sounder, 214.
Telegraph lines, construction of, 153.
  Covered wires for, 183.
  Poles, 153, 155.
Telegraph offices, hints for care of, 229.
Telegraphic circuits, 130.
  Faults in, 231, 233.
  Loops, 201.
  Systems still in use, 132.
  Testing for faults in, 233, 241.
Telegraphs, early experimental, 131.
  District or messenger-call systems, 137.
  Fire-alarm, 136.
  Operated by make and break of circuit, 140.
  Operated by reversals, 140.
  Police, 139.
  Stock-reporting, 139, 141.
  Type-printing instruments, 140, 141.
  Multiple, 242.
  Duplex, 242, 250.
Telegraphs—
  Electro-harmonic, 254, 265.
  Quadruplex, 250, 254.
Telephone, the, 299.
  Ader, 304.
  Battery telephones, 304.
  Blake, 307.
  Construction of, 316.
  Crossley's transmitter, 311.
  Crown, 303.
  Definition of word, 299.
  Dolbear's receiver, 314.
  Edison transmitter, 306.
  Hunnings's form, 313.
  Induction-coils for, 309, 351, 352.
  Magneto-telephone, 299.
  Operation of as transmitters 305.
  Patents, 351.
  Pony crown, 303.
  Standard Bell telephone, 302.
  Strength of current generated by, 353.
  Telephone switch, 315.
  Uses of, 316, 317.
Telephone lines, uninsulated, 183.
  Aerial cables for, 181, 183.
  Signals for, 297.
  Wire adapted for, 168.
Telephone switches, 200.
Telephonic communication through submarine cables, 190.
Testing for circuit faults, 233, 241.
  For cross, 239.
  For defective ground terminal, 240.
  For disconnection, 233, 235.
  For escape, 238.
  For ground, 237.
  For intermittent disconnection, 235.
  For intermittent ground, or cross, 239.
  For partial disconnection, 236.
  For weather-cross, 240.
Thermo-electric battery, 37, 39.
  Applications of, 39, 40.
Thermo-electricity, 20, 36.
  Discovered by Seebeck, 36.

Thomson's reflecting galvanometer, 107, 110.
Time-balls and guns, electrically operated, 328.

Underground lines, 184.
  Adaptation to telephony, 185, 188.
  Electro-static capacity of, 353.
  First laid, 184.
  Materials of conductors and insulators, 184.
  Retardation in, 188.
  Where laid, 185.
Units, employed in electrical measurements, 93, 97.
  Of capacity, 95.
  Of current, 95.
  Of electro-motive force, 94.
  Of quantity, 95.
  Of resistance, 94.
Universal switch, 197.

Vibrating electric bells, 287.
Volt, definition of, 94.
Volta invented electrophorus, 353.
Voltaic cell, 23.
  Battery, 24.
Voltaic electricity, 22.
  How it differs from frictional, 22.
Volta's pile, 26.

Weather cross, 233, 240.
Western Union pin-switch, 198.
Wheatstone bridge, 110.
  Description of, 110, 111.
  Explanation of principles involved, 111.
  Method of using, 111, 112.
  When introduced, 110.
Wire, to ascertain weight per mile from diameter, 174.
  For telephone lines, 168.
  Galvanized, 170.
  Killing process, 174.
  Mechanical and electrical tests for, 170, 173.
  Preferable sizes for long lines, 167, 168.
  Reason for preferring large wire, 167.
  Resistance, variation with temperature, 173.
  Sizes chiefly used, 165.
  Used for land lines, 165.
Wire for inside construction, 192.
  Arrangement of in offices, 192.
Wire-gauge, 166, 168.

Zincs, amalgamation of, 25.

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